A STUDY OF METHODS USED IN

MEASUREMENT AND ANALYSIS OF SEDIMENT LOADS IN STREAMS

REPORT NO. 5

LABORATORY INVESTIGATION OF SUSPENDED SEDIMENT SAMPLERS

DECEMBER, 1941

A Study of Methods Used in

MEASUREMENT AND ANALYSIS OF SEDIMENT LOADS IN STREAMS

Planned and conducted jointly by

Tennessee Valley Authority, Corps of Engineers,

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Iowa Institute of Hydraulic Research

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LABORATORY INVESTIGATIONS OF SUSPENDED SEDIMENT SAMPLERS

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The cooperative study of methods used in

MEASUREMENT AND ANALYSIS OF SEDIMENT LOADS IN STREAMS

covers phases indicated by the following report titles.

Report No. 1

FIELD PRACTICE AND EQUIPMENT USED IN SAMPLING SUSPENDED SEDIMENT

Report No. 2

EQUIPMENT USED FOR SAMPLING BED-LOAD AND BED MATERIAL

Report No. 3

ANALYTICAL STUDY OF METHODS OF SAMPLING SUSPENDED SEDIMENT

Report No. 4

METHODS OF ANALYZING SEDIMENT SAMPLES

Report No. 5

LABORATORY INVESTIGATIONS OF SUSPENDED SEDIMENT SAMPLERS

SYNOPSIS

This report presents the results of experimental studies of suspended sediment samplers. Various forms of simple intake tubes and typical suspended sediment sampler intakes were tested to evaluate errors in the sediment concentration of samples due to adverse sampler entrance conditions, deposition of sediment with flow through a horizontal cylinder, and loss of sediment in transferring the samples to other containers.

Tests were made with five representative slow filling samplers to determine their filling characteristics under various conditions of stream velocity, sampling depth, and sampler operation.

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LABORATORY INVESTIGATIONS OF SUSPENDED SEDIMENT SAMPLERS

I. INTRODUCTION

1. Scope of project--Measurement of the quantity and character of sediment transported by streams is an important activity common to river maintenance and development, stream discharge measurement, erosion control, irrigation, and hydro-electric development. A cooperative project has been sponsored by a number of Government agencies to study the various methods and types of equipment used in the measurement of sediment loads, with the ultimate aim of improving and standardizing them so that more analogous data will be secured.

From the standpoint of sampling equipment and technique, the movement of sediment has been classified as suspended load and bed load. The basic difference in their measurement is that the former is determined from a sample as the weight of solids per unit volume of water which, when correlated with water discharge, will give the quantity of suspended sediment transported in a given time, while the bed-load is measured directly as the weight of sediment moving past a unit of stream width per unit of time. This project was concerned primarily with the problems of suspended sediment determinations, but included, also, a brief review of bed-load and bed material sampling equipment.

The determination of the quantity and character of suspended sediment passing a selected stream cross section over a period of time, involves the following phases:

a. Selection of sampling points so that the samples can be properly correlated with the water discharge and the determination of the frequency of sampling.

b. Collection of samples from these selected points in such a manner and with such equipment that the samples will accurately represent the true water-sediment suspension at the points at the time of sampling.

c. Analysis of the samples for the sediment content, particle size gradation and any other sediment characteristics as required.

The studies of the various phases of suspended sediment determinations, together with the review of equipment used for bed-load measurements, are presented as indicated by the following titles of the respective reports:

Report No. 1. "Field Practice and Equipment Used in Sampling Suspended Sediment;" a review of sediment investigations which presents and discusses the various methods of selecting the verticals to be sampled in a stream section, the methods of selecting the sampling points in a vertical and the considerations in determining the frequency of sampling the particular stream section; and which describes, classifies, and discusses the numerous suspended sediment samplers.

Report No. 2. "Equipment Used for Sampling Bed-Load and Bed Material;" a review and classification of the various types of equipment.

Report No. 3. "Analytical Study of Methods of Sampling Suspended Sediment;" a hypothetical analysis of the various methods of sampling a stream vertical.

Report No. 4. "Analysis of Sediment Samples;" a presentation and study of the numerous laboratory methods of analyzing sediment samples for particle size and total solids concentration.

Report No. 5. "Laboratory Investigations of Suspended Sediment Samplers" as presented in this report is an experimental study of the basic principles of sampling action as affects the accuracy of the samples, and of the filling characteristics of representative types of slow filling samplers.

2. Purpose of experimental study of samplers--A number of features of samplers and sampling action have been visualized as sources of error in the sediment concentration in suspended sediment samples. A non-

representative sample may result from adverse entrance conditions into a sampler, from accumulation of sediment in the sample container, or from loss of sediment in transferring a sample. These factors, and the magnitude of their effects upon the samples, were investigated experimentally in this laboratory study.

From the review of sediment investigations as presented in Report No. 1, it was evident that there was a serious lack of exact knowledge of the filling characteristics of slow filling samplers, particularly the magnitude of their filling rates under various sampling conditions. The experimental study was conducted to provide this basic information necessary in the study of the field operation, in the analysis of errors resulting from the filling action, and in the design of a sampler.

3. Methods of study--The analysis of sampler entrance conditions constituted the major problem in the study of the errors in sediment content of samples. It required elaborate procedure and equipment and involved the largest number of tests. Entrance conditions were established which, logically, would cause errors, and the magnitude of the errors were evaluated, but no attempt was made to determine the actual flow patterns at the intakes. Samples were collected from suspensions of known concentration and errors in the sample concentrations were attributed to the particular entrance conditions. This procedure involved the circulation of a water-sediment suspension through a closed conduit from which test and standard samples were collected simultaneously from adjacent sampling points. The standard samples, collected under the most ideal entrance conditions, were used to establish the true sediment concentration

of the suspension at the sampling point, as no method of computing this concentration was devised.

The tendency toward deposition of sediment in the passage of a suspension through a horizontal cylinder was readily observed in a transparent cylinder placed in the flowing suspension. The phenomenon was studied quantitatively for several samples which were trapped in the cylinder.

To evaluate the tendency toward a loss of sediment in a sample transfer, caused by sediment adhering within the samplers, simple, direct tests were made. The procedure consisted essentially of emptying prepared samples of known concentration out of various samplers and of analyzing both the final sample and the residue in the sampler.

The study of sampler filling characteristics, of the various slow filling samplers, involved actual filling rate measurements under a range of conditions of stream depth, velocity, and sampler operation. A number of the tests were made in the deep, still water of an abandoned quarry, and the tests involving stream velocity were made in a large flume at the laboratory of the Iowa Institute of Hydraulic Research.

4. Authority and personnel--The cooperative project, of which this study is a part, was authorized and sponsored informally by the following Federal Government agencies: the Geological Survey, Indian Service, and Bureau of Reclamation of the Department of Interior; the Flood Control Coordinating Committee of the Department of Agriculture; the Engineer Department of the War Department; and the Tennessee Valley Authority. The studies were conducted at the Hydraulic Laboratory of the Iowa Institute of Hydraulic Research, State University of Iowa, under the

supervision of Professor E. W. Lane, consulting engineer. Engaged on the project as representatives of their respective cooperating agencies have been Cleveland R. Horne, Jr., Engineer Department; Victor A. Koelzer, Geological Survey; Donald E. Rhinehart, Bureau of Reclamation; Vernon J. Palmer, Flood Control Coordinating Committee; and Clarence A. Boyll, Tennessee Valley Authority.

The Iowa City Sub-Office of the St. Paul U. S. Engineer District under the direction of Martin E. Nelson, Engineer, assisted in the administration of the project, edited and published the reports and assisted in the design and construction of equipment and in the conduct of tests.

II. TEST EQUIPMENT AND EXPERIMENTAL MATERIAL

5. Test equipment--The experimental study of sampler entrance conditions required the development of special laboratory equipment which consisted essentially of: a conduit through which a water-sediment suspension was circulated as desired; special sampling apparatus permitting the collection of samples from the circulating suspension under carefully controlled sampling conditions; and regular laboratory equipment for analyzing samples.

No additional equipment was required for the study of sediment deposition in instantaneous horizontal samplers. For the evaluation of the loss of sediment in transferring samples the containers of several common samplers were used.

The tests of filling characteristics of samplers were conducted with five relatively common slow filling samplers, including both the bubbling type and the smooth filling type provided with separate air exhausts. The descriptions of the samplers tested and the alterations to adapt them for the tests, are given in Section 28. The main additional equipment consisted of a U. S. Geological Survey type sounding reel for suspending the samplers, and a Price current meter for measuring the stream velocity at the sampling point.

The conduit or circulating system as shown in Fig. 1, for the study of sampler entrance conditions, was composed of (1) a horizontal, rectangular conduit, 10 by 10 in. by 16 ft. long, as the main testing and observation section, (2) a 6-in. centrifugal sand pump, at the downstream end of the main section, for circulating the suspension, (3) a 6-in.

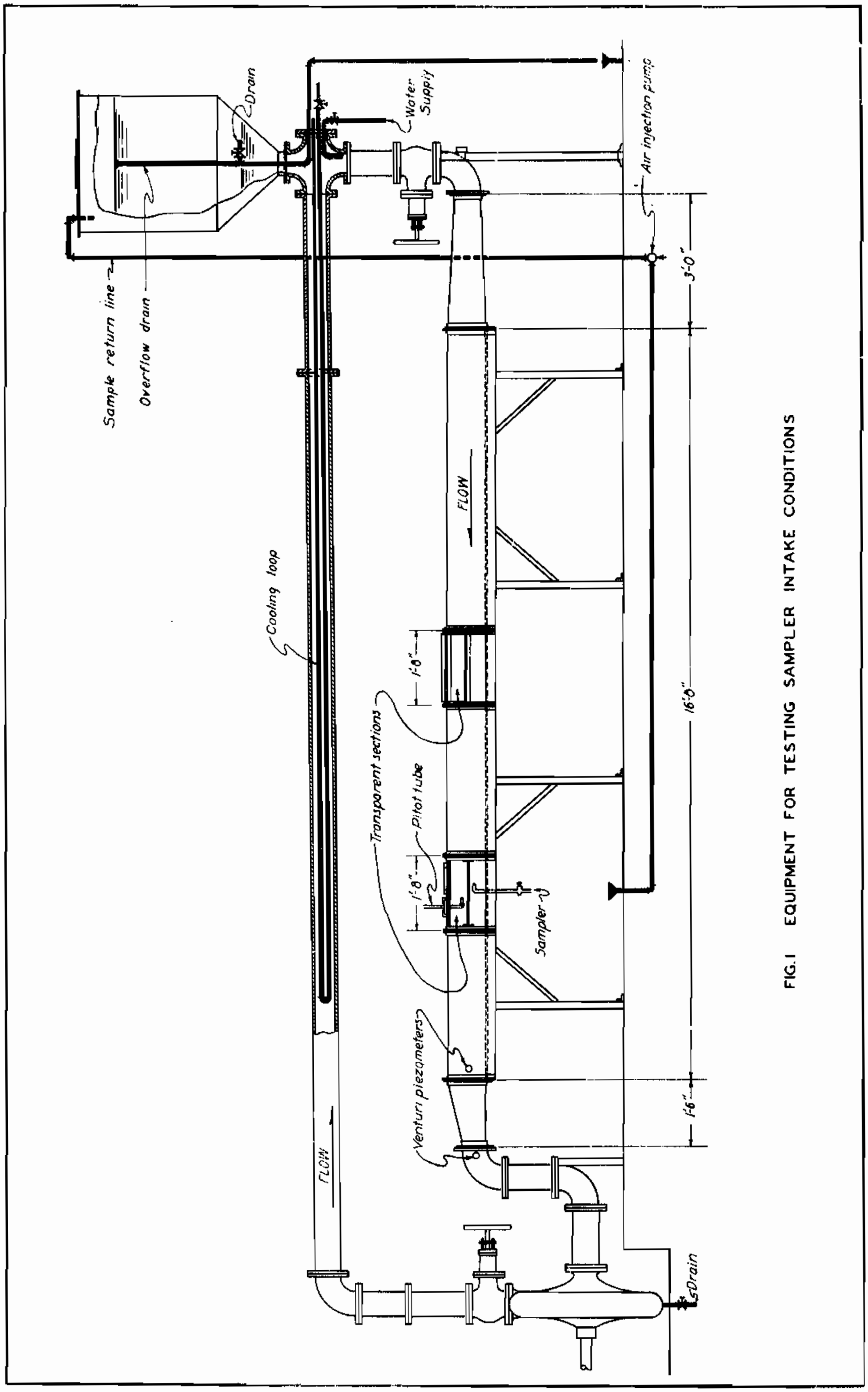


FIG.1 EQUIPMENT FOR TESTING SAMPLER INTAKE CONDITIONS

FIG. 1

cylindrical pipe line to carry the suspension from the pump to the upstream end of the main section, and (4) a reservoir or head tank connected to the system above the upstream end of the main section.

The main section, consisting of three sections, formed of 1/8 in. sheet steel and two transparent pyralin sections, was built on a single 16.8-ft. length of 10-in. 15.3-lb. steel channel. The channel, with flanges turned down, provided the smooth bottom of the conduit, and the formed sections were bolted over rubber gaskets to the flanges of the channel. The two transparent sections, built up of 1/4-in. sheet pyralin, were bolted to the adjoining steel sections and to the flanges of the channel. They provided observation and test sections, the downstream one being equipped and used as the sampling station.

A reconditioned, 6-in., Morris, centrifugal sand pump, model 1911, belt driven by a 30 hp. electric motor, was used to circulate the suspension. It had a maximum capacity of 3.8 c.f.s., which provided 5.5 ft./sec. velocity at the sampling station. One disadvantage in the use of this pump, after it was cleaned of rust, was the somewhat pulsating nature of its discharge.

The tank, connected indirectly into the conduit above the upstream end of the main section, functioned as a pressure control and reservoir, and provided a means of adding sediment and water to the suspension to replace that withdrawn as samples. It also served as a reservoir into which the entire suspension from the main section could be pumped and saved while alterations were made at the sampling section. As the circulating suspension did not flow through the tank, the water in the tank normally was tranquil, undisturbed, and free from sediment. The water pressure in the tank was transmitted directly to the system, resulting in operating pressures above atmospheric throughout, and thereby preventing the suction of air through small leaks into the circulating suspension.

A 3/4-in. water supply line was tapped into the conduit below the tank and faced to direct its supply in the direction of the circulating suspension. Faced in this way, the danger of sediment accumulating in this pipe was eliminated. In addition to its use for initial filling of the system, the line provided a clean water supply during operation, which, in conjunction with the overflow drain in the tank, allowed a continuous exchange of the water without affecting the sediment of the suspension.

A drain pipe, installed through the center of the tank and open at the top about 6 in. below the top of the tank, acted as a constant level, overflow drain. This pipe was tapped with a valve-controlled opening 2 ft. below the overflow level, whereby the water of the tank could be drained as desired. By using the overflow drain, the used, somewhat discolored water of the suspension could be drained as fresh water was added through the supply line. The sediment of the suspension was prevented from rising into the tank by the slow rate of this operation; the upward velocities in the tank were lower than the fall velocities of the sediment.

A 1-in. drain pipe, tapped into the bottom of the pump, provided means for completely draining the entire system. The valve controlling this drain was placed immediately below the pump to minimize the amount of sediment that could accumulate in the drain during operation.

Flow of the circulating suspension was regulated by throttling the discharge of the pump with a 6-in. gate valve. A second 6-in. gate valve, located just downstream from the tank connection, remained open during operation and was used only when the suspension was pumped out of the main section for storage in the tank.

6. <u>Accessories for operating the circulating system</u>--Flow meters were used to measure the rates of discharge of the circulating suspension and cooling water was used to regulate the temperature of the suspension. A pitot tube, calibrated in a rotating, circular trough was used to measure velocities at any point in the sampling section. It was connected to a differential manometer whose scale was sloped to magnify the readings by five. The scale was graduated so as to indicate velocities directly in feet per second.

The transition from the rectangular to the cylindrical conduit at the downstream end of the main section was used as a venturi meter to measure the rate of flow in the system. It was calibrated in place by use of a separate water supply and a weighing tank. A pair of piezometers at the large end and another pair at the small end of the transition were connected to a differential manometer which was equipped with a scale graduated to indicate flow directly in cubic feet per second. Separate calibrations, with and without the pump in operation, showed that the pump, downstream from the venturi meter, did not affect the accuracy of the discharge readings. A comparison of the rate of flow as indicated by the venturi meter with that computed from the pitot tube velocity readings in the sampling section served to verify satisfactorily the individual calibrations of these instruments.

A temperature rise in the suspension of about 8° F. per hour was observed during the operation of the circulating system. In order to maintain uniform temperature a cooling system was installed consisting of a 36-ft. length of 3/4-in. copper tubing doubled and extended into the 6-in. pipe line from the cross connection under the tank. Tap water circulating through this copper tube provided sufficient cooling and allowed regulation of the temperature of the suspension to any desired temperature above that of the water supply. The continuous exchange of water of the system by use of the water supply line and overflow drain of the tank provided an additional means of regulating the temperature.

7. Sampling apparatus used in study of sampling action--Equipment for collecting samples of the circulating suspension consisted principally of:

a. An assortment of sampler nozzles which were designed as readily interchangeable inserts, to seat with a taper lock joint into the mouth of withdrawal tubes.

b. Specially shaped brass tubes for withdrawing samples out of the conduit, which were equipped with stop cock valves for controlling the sampling rate and provided with a tapered mouth as a seat for the various nozzle inserts.

c. Necessary plates and watertight bushings installed in the transparent sampling section of the conduit to facilitate the insertion and adjustment of the sampling tubes and pitot tube to any desired point in the section.

d. An air injection pump for returning the water-sediment discharge of the samplers to the head tank when it was not retained as a sample.

The testing section of the conduit and the sampler nozzles and tubes for withdrawing the samples are shown in Fig. 2.

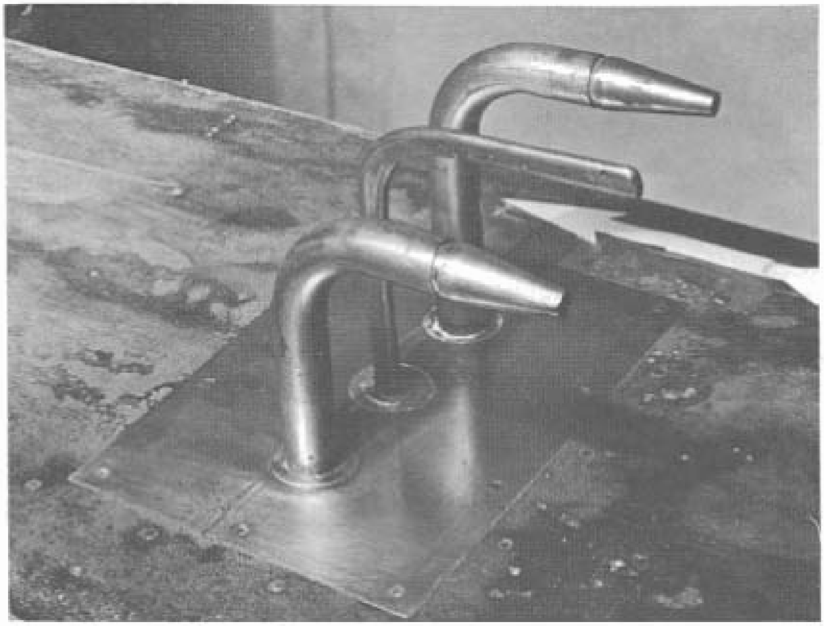
The nozzles are described individually and details and dimensions are given in the discussions of the respective test results. They were machined from heavy wall brass tubing or brass cylinders to the desired shapes and dimensions, and the critical dimensions were held to within 0.001 in. The back ends of the nozzles were machined on a standard taper of 4° included angle, to seat and lock into the similarly tapered mouth of the sample withdrawing tubes. They seated firmly but could easily be twisted out of this joint and interchanged.

The tubes for withdrawing the samples were of heavy wall brass tubing in two sizes: 9/16-in. and 3/8-in. outside diameter. The assortment included those bent to face the nozzles directly into the stream or at slight angles to this direction, to face the nozzles horizontally but across the direction of flow, and to face the nozzles vertically.

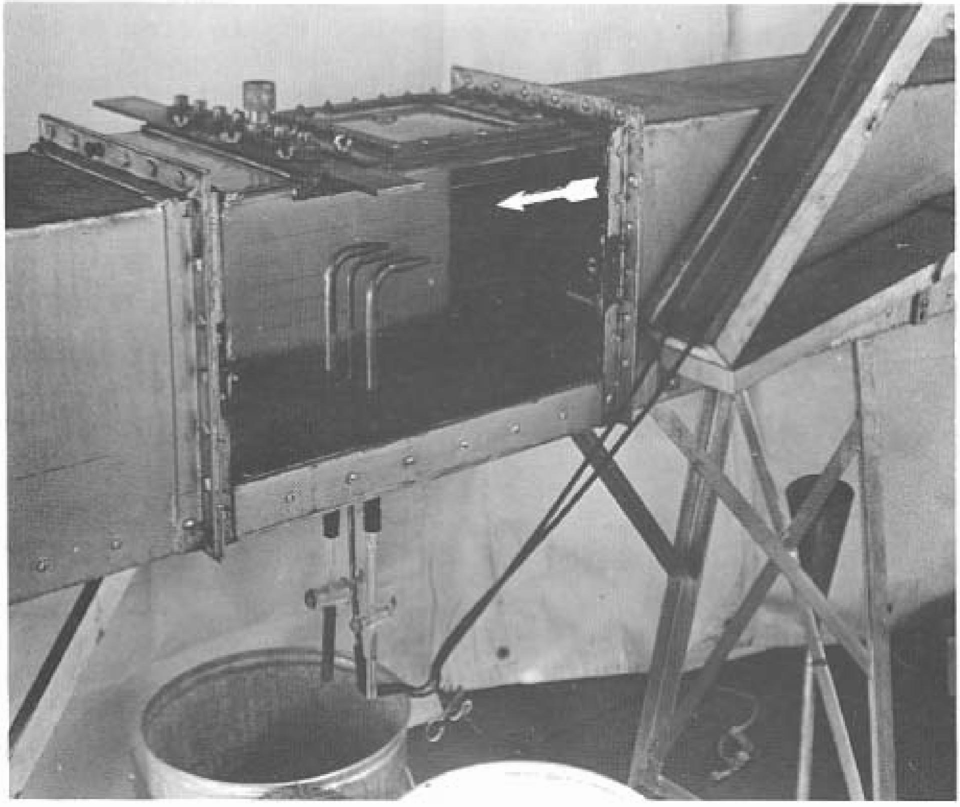
The bushings installed in top and bottom of the testing section were designed to accommodate either of the two sizes of sampling tubes and to allow their adjustment vertically in the stream. A removable plate 4 in. long and 6 in. wide, inserted in the bottom of the conduit with its top surface flush with the bottom of the channel, contained three bushings, spaced 1-1/2 in. center to center, which throughout most of the testing accommodated the pitot tube and two sampling tubes arranged symmetrically.

A plate in the top of the section, designed to slide across the conduit, contained bushings at 1-1/2-in. centers so that as many as seven could be used simultaneously. This feature was not used in the tests, but was convenient in the study of the sediment and velocity distributions throughout the sampling cross section, for which a sampling tube or the pitot tube was installed and moved to any desired point over the section.

A readily removable 8 by 8-in. plate was provided in the top of the



a. Duplicate sampler nozzles and pitot tube.



b. Sampling station in conduit.

Fig. 2 - Sampling apparatus.

transparent section, just upstream from the sliding plate. It provided easy access into the conduit to allow installation of sampler nozzles or other alterations of test conditions.

The air injection pump allowed continuous operation of the samplers without a depletion of the suspension in the system. Water and sediment, withdrawn through the samplers, but not collected as samples, was returned to the head tank.

8. Water and sediment used in tests of sampling action--Filtered and chlorinated Iowa River water of the regular University of Iowa supply was used throughout the tests. During the program of testing, the temperature of the water varied from about 40° to 80° F., but the temperature of the suspension during tests was controlled within a range of from 65° to 85° F., which range was found to have no perceptible effect upon the test results. In previous experiments it had been found that the water tended to cause floculation of fine grained sediments, but this was not evident in these tests because of the large sizes of sediment and the technique used. The water was treated with potassium dichromate, 0.02 per cent concentration, to inhibit rusting inside the pump and conduit. This practice was found to have no effect upon test results.

The sediment used consisted of four different, readily obtainable, commercial sands, differing principally in size as represented by the size analysis curves in Fig. 3. They are designated and referred to by the mean particle size which on the size analysis curve is the particle diameter corresponding to the 50 per cent ordinate.

The behavior of suspended sediment under various sampler entrance conditions is more directly a function of the fall velocity of the sediment particles than of the particle diameters. The fall velocity, or rate at which the particle falls through water under the force of gravity, is a function of the particle mass, size, shape, and surface properties, and of the water density and viscosity. Thus, it provides a more general basis for comparing the action of various sediments. Fall velocities of the material used in these tests under the usual conditions and with the native water are shown by Fig. 4.

It was advantageous in this study to work separately with the narrow ranges in size of sediment to show the relation of the particle size to its action under the various sampling conditions.

The 0.45-mm. Ottawa flint silica and the 0.15-mm. Ottawa banding sand consisted of natural, well rounded, uniform particles of a sufficiently narrow size range for use as purchased. The 0.06-mm. ground flint sand was graded in a hydraulic sand separator to the size range shown. The particles of the latter were more angular and less uniform than were the Ottawa sands. The smallest sediment, 0.01-mm. ground Wausau quartz, was used as purchased.

Samples of the sediment were taken from the system after various periods of operation and were analyzed to determine the amount of breaking or wearing down of particles. From these tests it was found that 12 to 14 hours of operation would result in a noticeable but unimportant increase in the percentage of finer particles due to wearing and breaking of larger particles. To insure that the reduction in the sediment size should not affect the test results, the suspension was drained after each 6 to 8 hours of operation, and replaced with fresh sand and water.

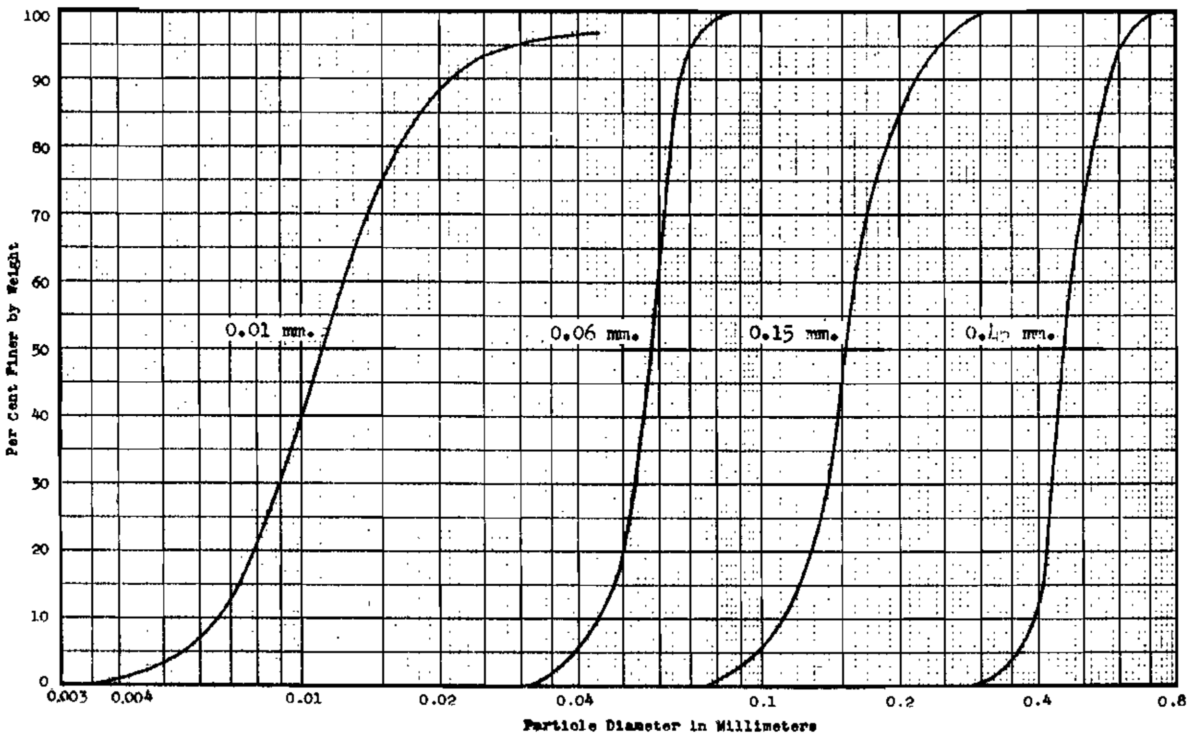


Fig. 3 - Size gradations of test materials.

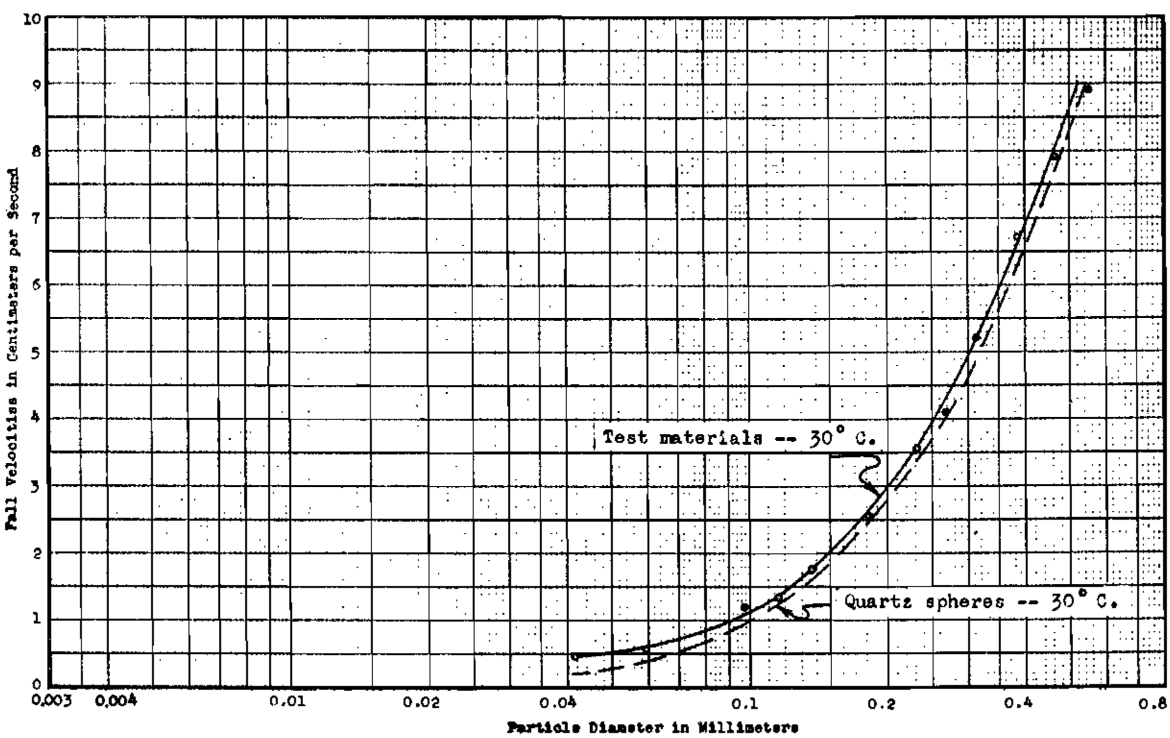


Fig. 4 - Fall velocities of test materials.

FIGS. 3 & 4

9. Operating characteristics of circulating system--A preliminary study of the operating characteristics of the circulating system was made to verify the reliability of the general procedure and to establish the operating and sampling technique. This study included observations of velocity across the sampling section, the nature of the flow through the conduit, the variation of sediment concentration with time and sampling point, and the distribution of sediment at the sampling section and throughout the system.

Results of the velocity observations throughout the sampling section, shown in Fig. 5, indicate a uniform, symmetrical distribution. Although of a pulsating nature, the flow in the system would remain constant over long periods of operation. The maximum velocity obtainable at the sampling section was about 5.5 ft./sec., corresponding to the maximum pump discharge of 3.8 c.f.s. The minimum velocity was restricted only by the sediment size, and was the lowest velocity at which a particular sediment would remain in suspension.

In order to study the characteristics of the sediment suspension, it was necessary to collect and analyze samples of the water-sediment mixture. The technique established for that purpose was devised with thorough consideration of the forces affecting the accuracy of a sample which are discussed more fully in Section 10. A thin, sharp-edged sampling tube, facing directly into the flow was used, into which the sampling rate was carefully controlled so that the velocity at the tube entrance was equal to the undisturbed stream velocity. This technique was assumed to give a sample whose concentration was truly representative of the sediment concentration in the system. The logic of this assumption is discussed more in detail in Section 11.

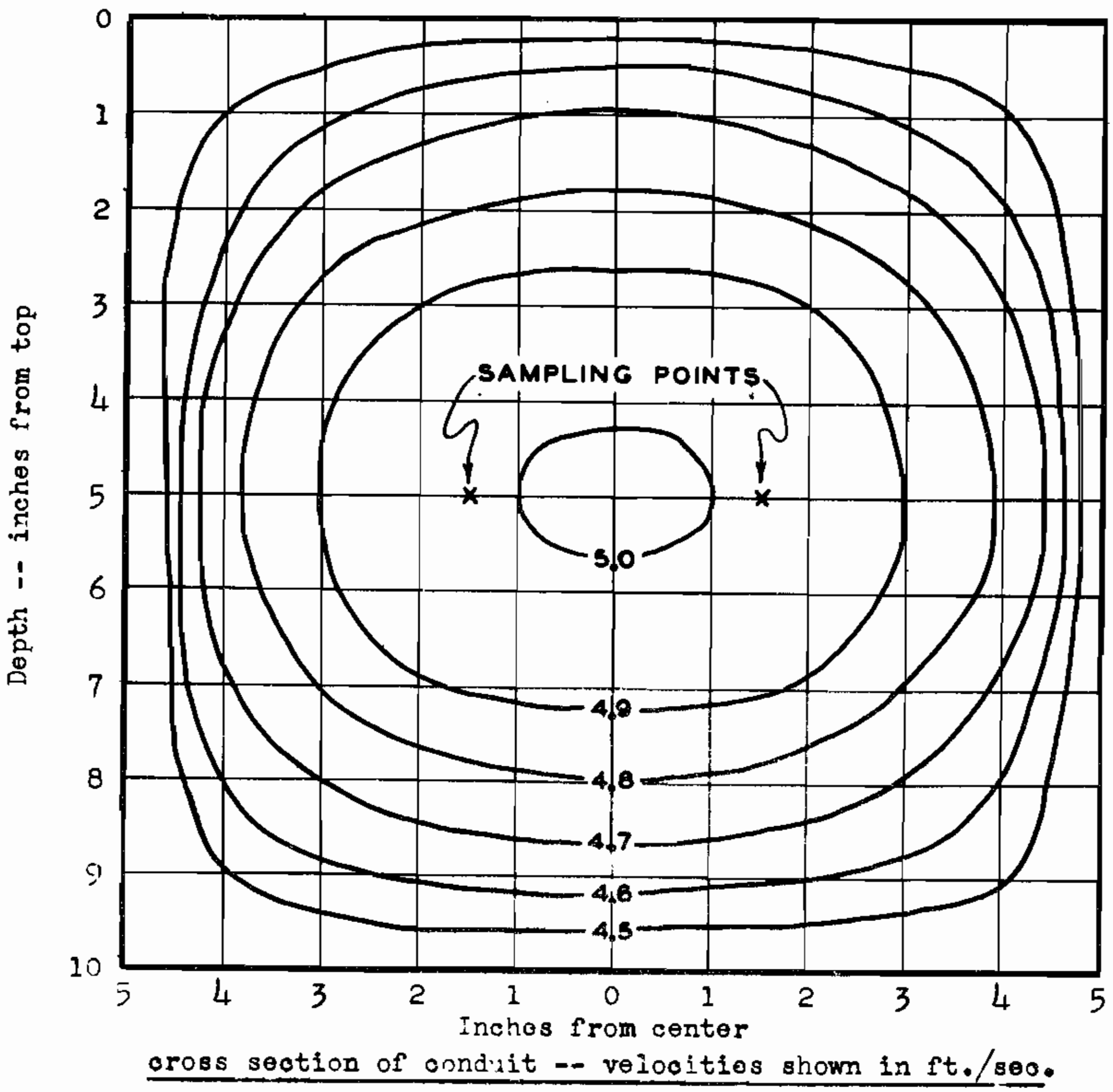


Fig. 5 - Velocity contours at sampling station.

A study of the variation with time of sediment concentration at a sampling point was combined with a comparative study of the sediment concentration at two sampling points, symmetrically located in a horizontal plane. Two samplers were installed in the sampling section with their mouths at arbitrarily selected points indicated in Fig. 5, and a series of successive samples were collected from each of the two points simultaneously. The results of the study are presented graphically in Fig. 6. The concentration of the successive 20-sec. samples varied over a range

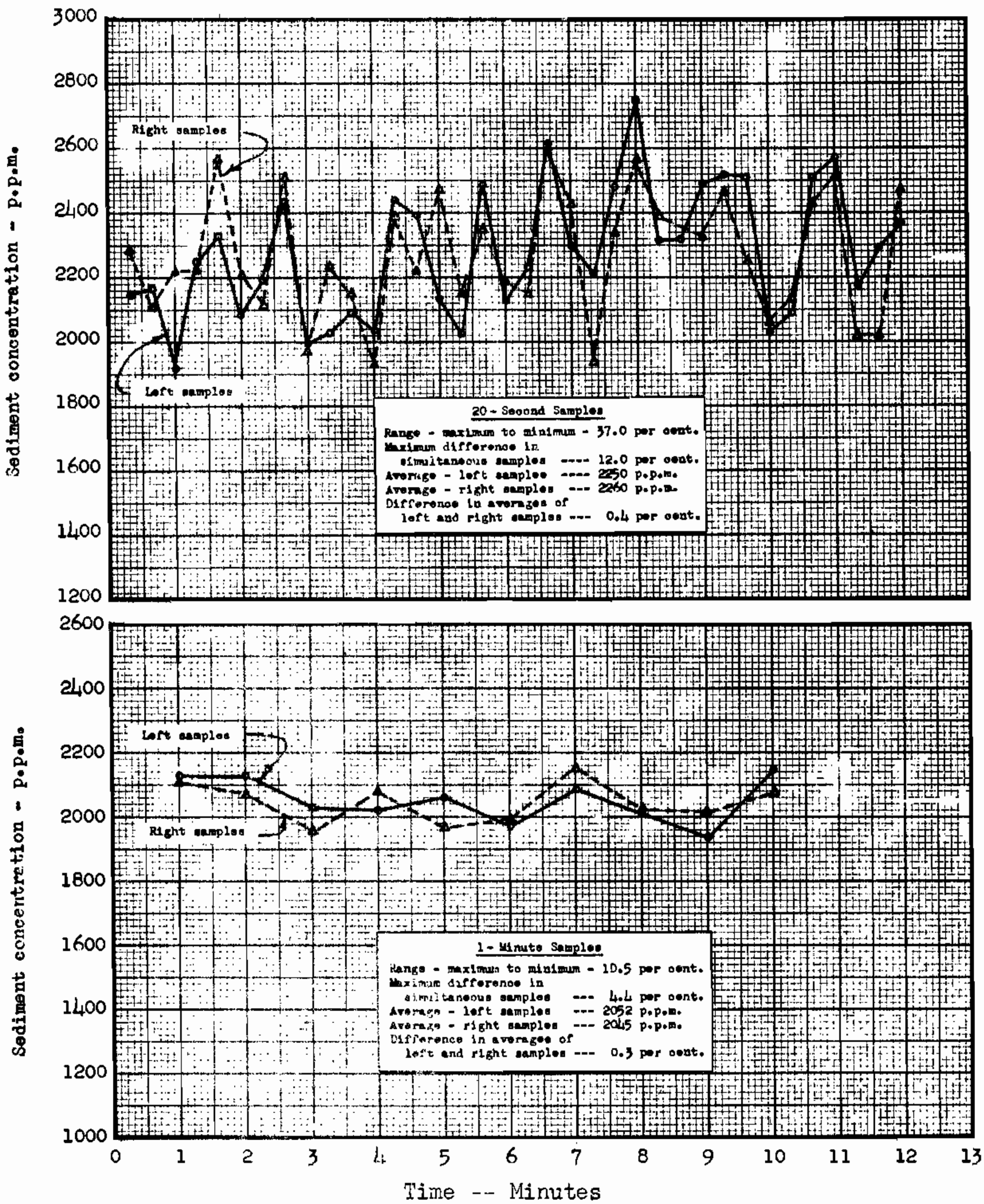


Fig. 6 - Fluctuations of sediment concentration at duplicate sampling points.

of 37 per cent of the mean concentration, and the concentration of the successive 1-min. samples varied over a range of 10.5 per cent. These fluctuations in the concentration were attributed partly to ordinary turbulence and partly to the pulsating nature of the flow. Their effect was minimized by sampling over long periods of time, usually about 10 min.

The simultaneous samples from the two sampling points showed much closer agreement than did successive samples from the same point. The maximum difference in concentration between two simultaneous 20-sec. samples was 12 per cent, and the average concentrations of the series of left and right samples differed only 0.4 per cent. This established the validity of simultaneous sampling, whereby the concentration measured with a standard sampler at one of a pair of symmetrical sampling points was considered to be the true concentration at the other test sampler point.

To study the sediment distribution at the sampling section, a sampler was placed at the center of the sampling section and samples of 10-min. duration were collected to establish the true concentration at that point. Operating simultaneously with the fixed sampler, another was moved from point to point vertically and horizontally throughout the section, collecting a sample at each point which was compared with the corresponding sample at the center. The sediment distribution found for different particle sizes is shown in Fig. 7. The concentration of sediment varied over the depth of the conduit as expected, that is, concentrations increased toward the bottom. It varied symmetrically across the conduit, the maximum concentration being at the center. Two sampling points at the same depth and symmetrically located across the section had the same average concentration of sediment, which verified the findings in previous tests.

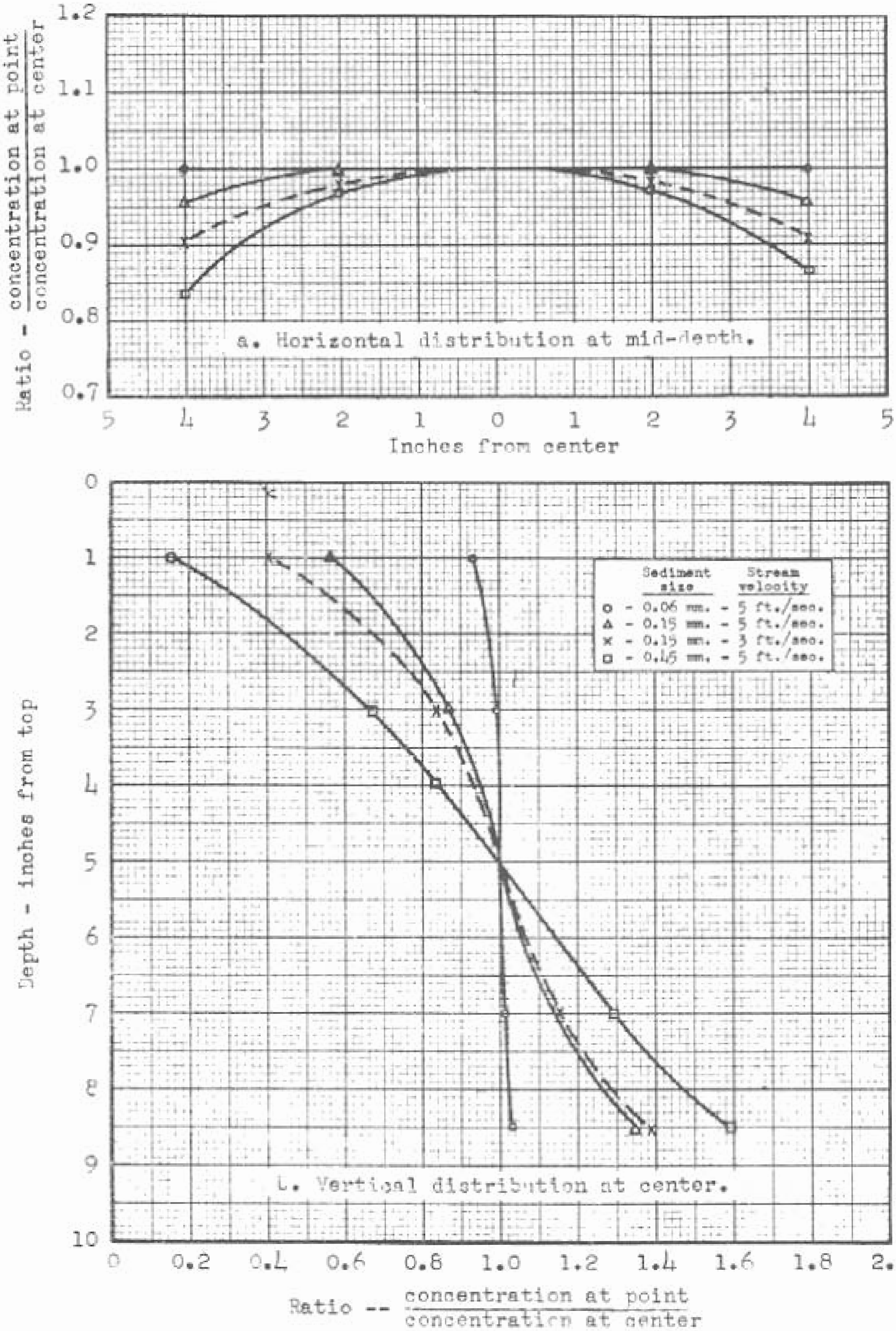


Fig. 7 - Sediment distribution at sampling station.

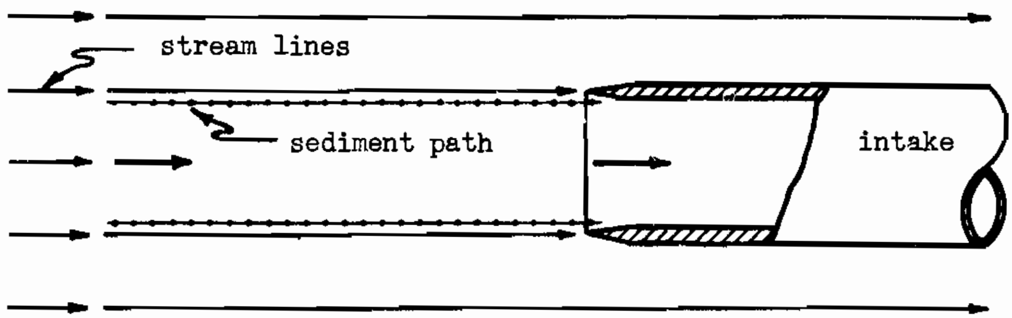
FIG. 7

The distribution of sediment throughout the system varied with the size of sediment, the rate of circulation, and possibly with other factors. The concentration at any point was not found to have a readily ascertainable relation to the average concentration of the suspension. Therefore, it was not practicable to compute the true concentration at a sampling point nor to attempt to control it to any predetermined value.

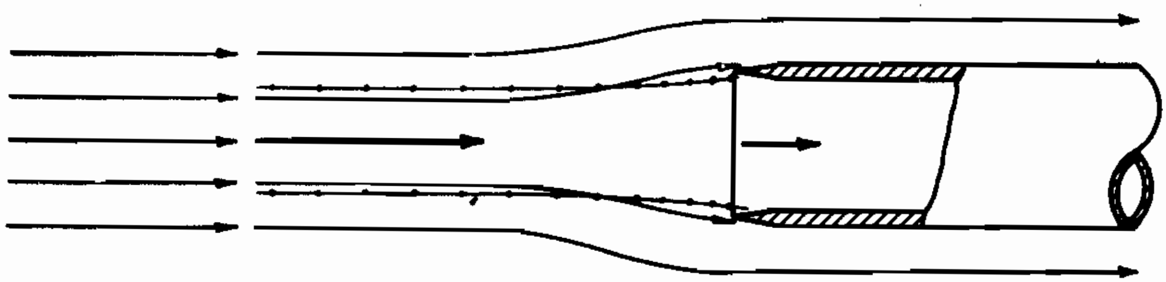
III. TESTS OF SAMPLER ENTRANCE CONDITIONS

10. Flow patterns at the entrance--Conditions at the mouth of a sampler may be represented by the flow pattern of the water-sediment suspension approaching and entering the sampler. It is logical that any curvature in this flow pattern, or in any of its stream lines caused by changes in velocity of direction, or by disturbances due to the sampler itself, will tend to segregate the sediment from the water. This, in turn, will change the concentration of sediment in the filament entering the sampler and, consequently, also in the sample collected. This tendency is due to the difference in density of the sediment and the water; the sediment, having greater density and inertia than the water, responds less rapidly than the water to forces changing its motion. The magnitude of any error in the sediment content of a sample resulting from this phenomenon would be a function of the particular flow pattern established and of the characteristics of the sediment.

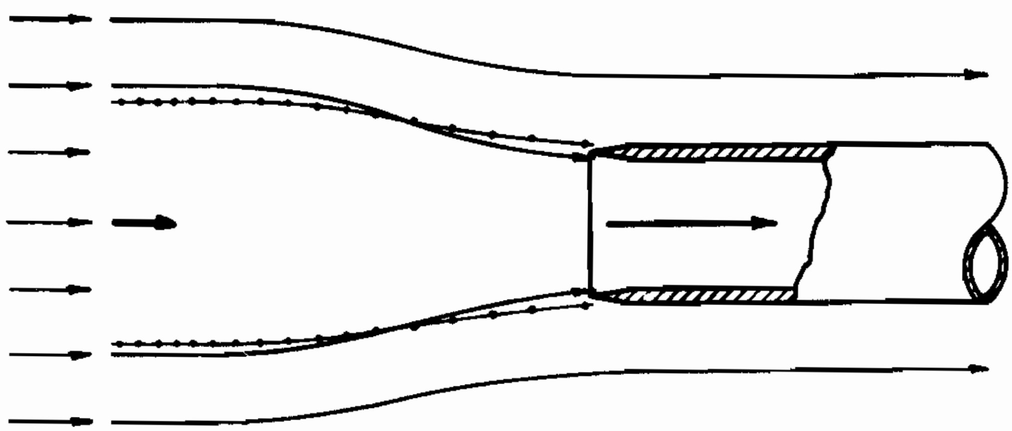
This phenomonon is illustrated qualitatively in Fig. 8 for three patterns of flow into a sampler whoso mouth faces directly into the stream. In Fig. 8b is represented the common case in which the sampling rate is slow, and the velocity in the mouth of the sampler is less than the natural stream velocity some distance upstream from the sampler. This condition is pictured by a filament of the suspension diverging in cross sectional area and decreasing in velocity as it approaches the mouth of the sampler. The sediment from just outside the border of the sampled filament, diverging less rapidly than the water, enters the mouth of the sampler as an excess. In Fig. 8c is represented the converse of this condition in which the velocity at the mouth of the sampler is greater



a. Normal sampling rate -- intake velocity equal to stream velocity.



b. Sampling rate below normal -- as illustrated, ratio of intake velocity to stream velocity approximately 1/3.



c. Sampling rate above normal -- as illustrated, ratio of intake velocity to stream velocity approximately 3 .

Fig. 8 - Flow patterns at mouth of sampler intake.

FIG. 8

than the natural stream velocity. The sediment in the sampled filament tends to converge to a lesser degree than the water, resulting in a sample too low in sediment concentration.

Conditions of similar nature may be prevalent with all types of samplers and the corresponding flow patterns may be conveniently demonstrated by injecting streams of dye into the suspension. A demonstration of this nature has been made recently at the California Institute of Technology(1) using several existing samplers.

The tests which follow are concerned directly with the quantitative evaluation of errors in samples resulting from these phenomena.

11. General procedure in testing sampler intakes--The general procedure followed in the tests to evaluate the effect of sampler entrance conditions involved collecting test samples under various intake conditions and comparing their sediment concentrations with the true concentration at the sampling point. As previously stated, the value of the true concentration was necessarily established by sampling, but this was done under carefully controlled "standard sampling conditions" devised with thorough consideration of the physical forces affecting the accuracy of a sample. These standard sampling conditions were defined as those in which the approaching filament of water-sediment suspension was not deflected or disturbed in any manner until it reached the mouth of the sampler.

The standard sampling conditions were attained by:

a. Using the standard sampling nozzle, shown in Fig. 9, which was designed to minimize its effect upon the approaching suspension.

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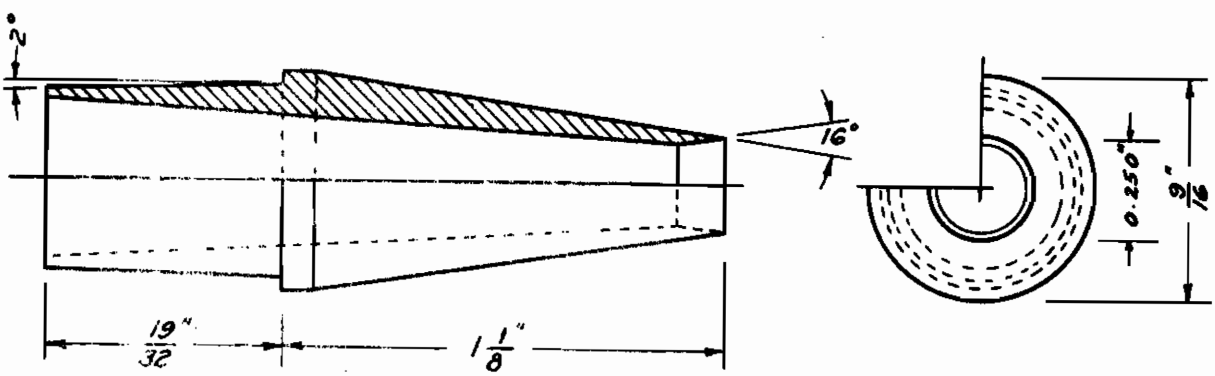
(1) American Geophysical Union, Transactions 1940, Part I, p. 78, "The Use of Hydraulic Models in the Design of Suspended Load Samplers" by J. Pat O'Neill.

b. Facing the nozzle directly into the flow (normal position) so that a sample would undergo no change of direction in entering the sampler.

c. Controlling the sampling rate so that the velocity in the mouth of the sampler would be equal to the undisturbed velocity in the stream as illustrated in Fig. 8a, and no change in velocity or direction would result as the sample was collected.

With this minimum of disturbance and change of flow of the sample as it approached and entered the sampler, no forces were visualized which might tend to affect the accuracy.



Sectional and side view

End view

Fig. 9 - Standard nozzle intake diameter 0.25 in.

Further, from the study of the sediment suspension characteristics at the sampling section, Section 9, it was established that:

a. Samples collected over long periods of time, 5 to 10 min., provided a satisfactory average of the fluctuating concentration.

b. Values of sediment concentration, based on long samples, are the same at two sampling points symmetrically located in a horizontal plane.

Based on these fundamental assumptions and characteristics, the procedure involved collecting, from twin sampling points, a test and a standard sample simultaneously over a 10-min. sampling period. Any difference between the sediment concentration of the test sample and that of the standard sample was attributed as an error due to the particular sampling conditions in the test sampler.

12. Outline of tests--All sampling conditions were arranged and classified according to their deviation from the assumed standard sampling conditions in the following manner:

a. Deviations from the normal sampling rate.

b. Deviation from the normal position of the sampler nozzle.

c. Deviations in size and shape of the nozzle.

d. Disturbance of sample by nozzle appurtenances.

e. Major variations from standard conditions in the orientation of sampler nozzle.

These deviations are likely to occur in various combinations and their effect should vary with sediment size and stream velocity. Tests were conducted in an order arranged to evaluate their effects separately and in probable combinations.

Each test consisted of a series of samples collected at intake rates from about 25 per cent to about 300 per cent of normal, with a single size of sediment, a single stream velocity, and one nozzle placed in one position. Thus each test showed the effect of deviations from normal intake rates either alone, or in combination with any other desired deviation from standard conditions.

13. Technique in collecting and analyzing samples--The technique followed in collecting and analyzing the samples allowed an immediate determination of their sediment concentrations, and resulted in a high degree of accuracy.

The sampling period of 10 min., established in the study of fluctuations of sediment concentration at the twin sampling points, Section 9, resulted in large volumes of water and sediment in each sample. The samples, usually in volumes from 5 to 50 gallons were weighed directly. The sediment was separated from the water either by sieves or sedimentation and was weighed directly in the wet condition by a water displacement method. This method consisted in determining the difference in weight of a given volume of water and an equal volume of the water-sediment mixture. Equal volumes were obtained by measurement in volumetric flasks. This difference, the buoyed up weight of sediment, multiplied by the specific gravity of sediment and divided by the difference in specific gravity of sediment and that of water gave the true weight of dry sediment. The ratio of the dry weight of sediment to the weight of water gave the sediment concentration of the sample which could be expressed in per cent or in parts of sediment per million parts of water-sediment, p.p.m.

In preliminary studies of the sediment suspension characteristics, where smaller samples were collected, these were analyzed separately by siphoning off the water and drying the sediment. This method was used also to verify the accuracy of the displacement method of determining the quantity of sediment in the samples.

The mean sampling rate for each sample was computed from the total volume of the sample and the time of sampling. The velocity at the mouth of the nozzle was determined by dividing the sampling rate by the area of the nozzle mouth, and was usually expressed as a ratio to the normal or undisturbed stream velocity. The "normal" sampling rate was that resulting in a velocity at the mouth of the nozzle, intake velocity, equal to the normal or stream velocity. The area of the nozzle mouth was that defined by the sharp edge.

14. Errors in sediment concentration of samples collected with standard sampler nozzle--Tests were made to evaluate the effect of deviations from the normal sampling rate upon the samples collected, and to show the importance of controlling the sampling rate into a sampler. A series of samples collected at rates varying from about 1/4-normal to about 3-normal, with a single size sediment and a single stream velocity, comprised one test. The standard nozzle, shown in Fig. 9, was used, oriented in the normal position so that any effect upon the flow pattern of the sampled filament and consequently any error in the sediment concentration of the sample could be attributed to the particular deviation of the intake rate from normal alone.

Results of four tests with a stream velocity of 5 ft./sec., and suspensions of 0.45-mm., 0.15-mm., 0.06-mm., and 0.01-mm. sands are shown on Figs. 10 to 12. These data show that appreciable errors in the sediment concentration of a sample result from an incorrect or uncontrolled sampling rate. Samples collected at rates such that the velocity in the mouth of a nozzle is less than the normal stream velocity contain an excess of sediment, while samples collected at rates above normal are low in sediment content. Errors resulting from sampling rates below normal are considerably larger in magnitude than errors resulting from comparable deviations in sampling rate above normal. The errors increase in magnitude as the sampling rate increases above normal.

Results of three tests using 0.15-mm. sediment with stream velocities of 3, 4, and 5 ft./sec. are shown together on Fig. 13. From these data it

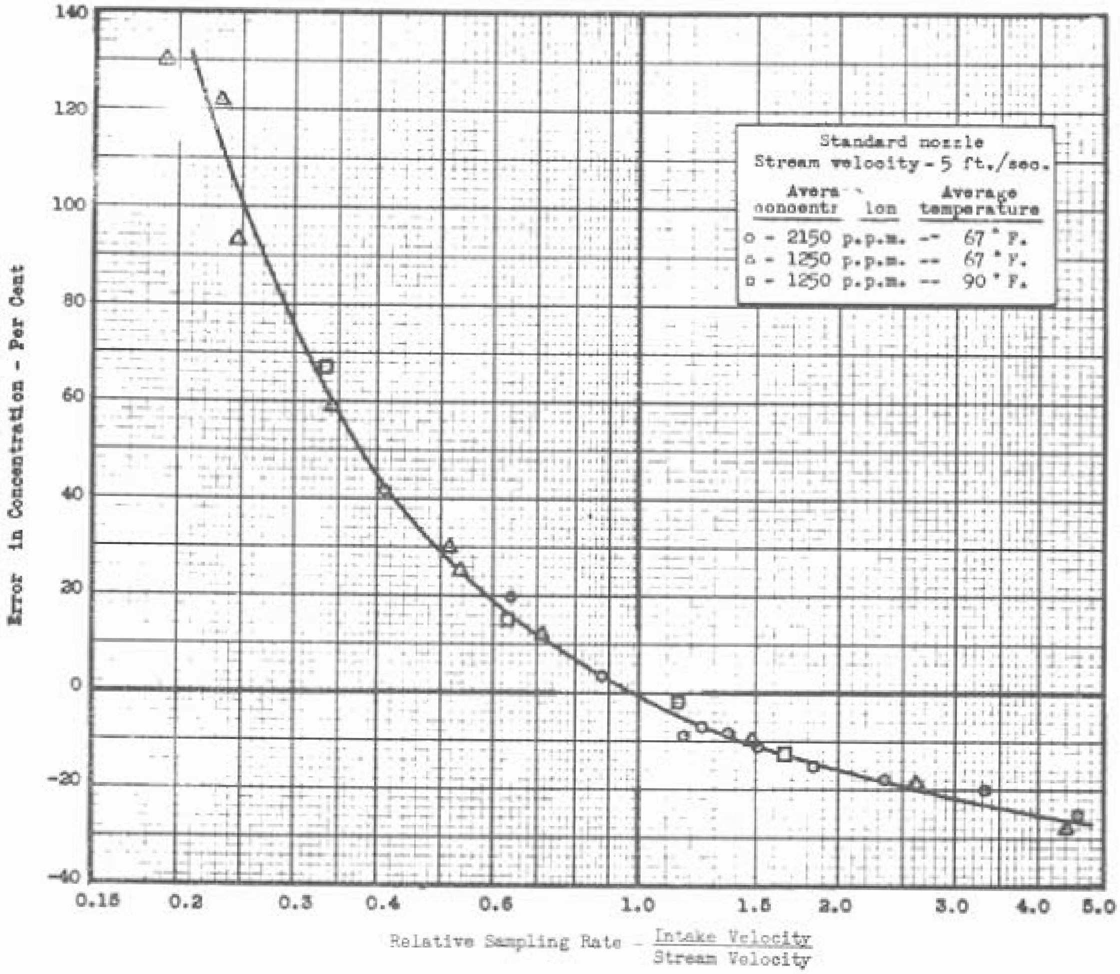


Fig. 10 - Effect of sampling rate on sediment concentration -- 0.45 mm. sediment.

is evident that the actual velocity of the flowing stream affects the magnitude of the errors caused by deviations from the normal intake velocity, higher velocities resulting in somewhat larger errors. But the effect of variations in stream velocity is relatively smaller than the magnitude of errors caused by deviation from normal intake velocity, so that tests made at any stream velocity are representative of a large range of velocities.

To emphasize the relation between sediment size and the magnitude of the errors, the data in Figs. 10 to 12 are replotted on Fig. 14 to show

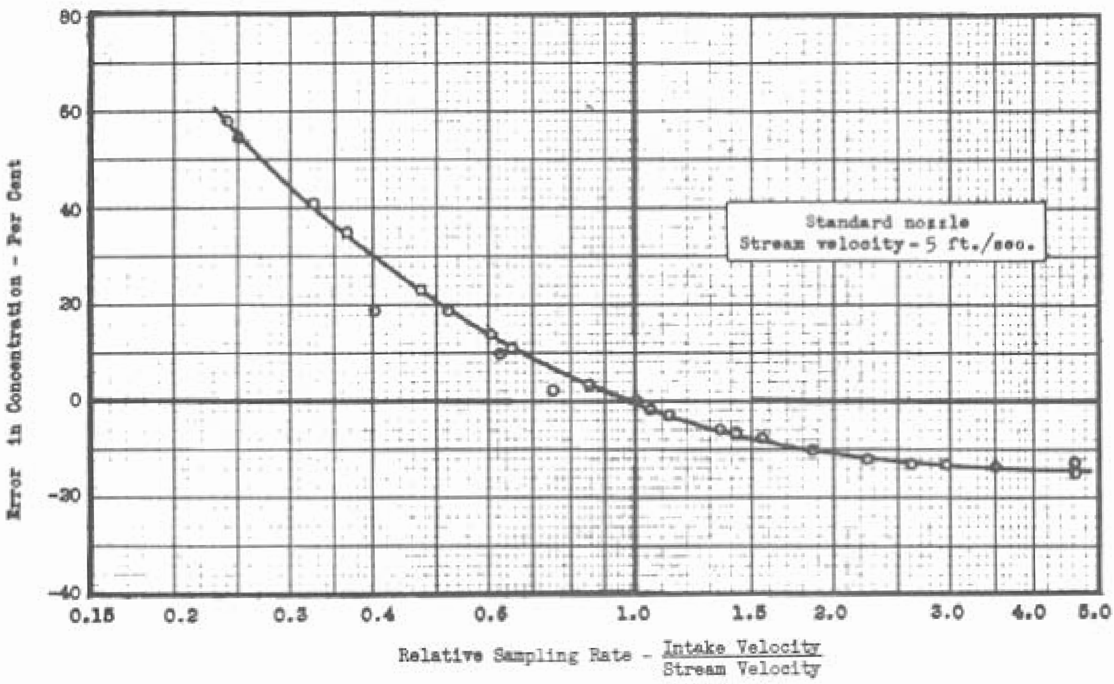


Fig. 11 - Effect of sampling rate on sediment concentration -- 0.15 mm. sediment.

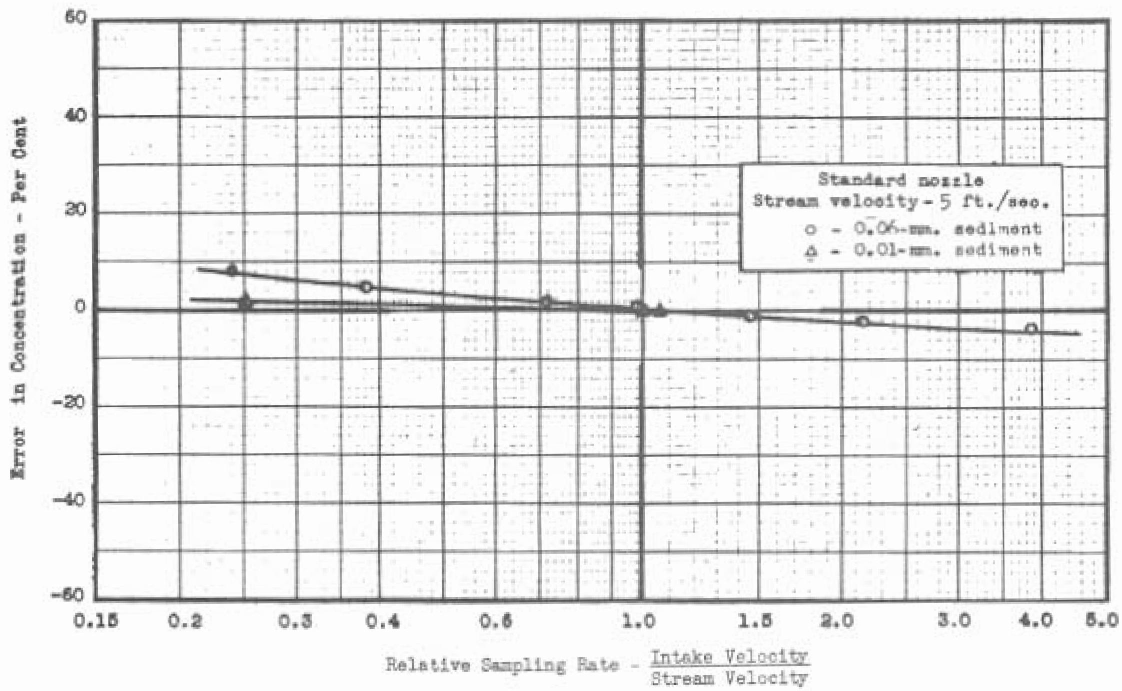


Fig. 12 - Effect of sampling rate on sediment concentration -- 0.06 mm. and 0.01 mm. sediments.

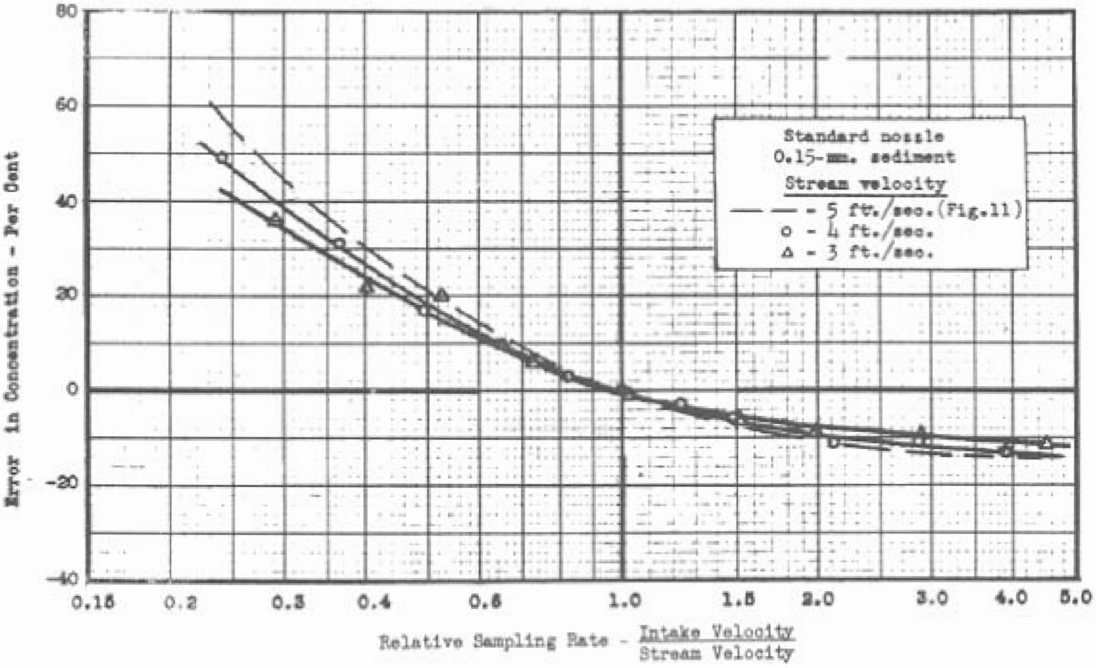


Fig. 13 - Effect of stream velocity on errors in sediment concentration.

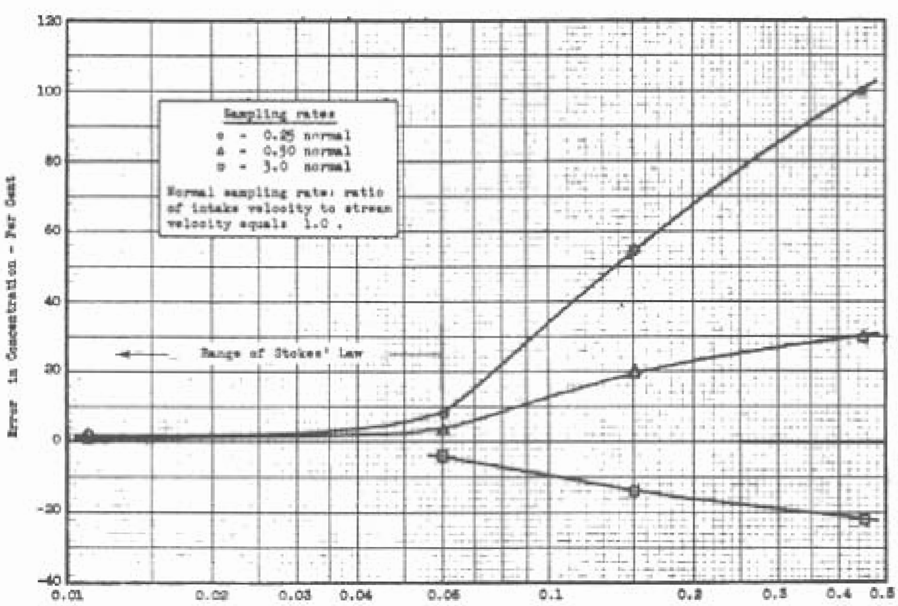


Fig. 14 - Relation of sediment size to errors in sediment concentration.

the error in concentration of samples as a function of the size of sediment for several sampling rates. As the size of sediment increased above 0.06-mm., the magnitude of the errors in sediment concentration of the samples increased rapidly. Within the range of Stokes' Law, sediment sizes below 0.06-mm., the errors were comparatively small in magnitude and varied less rapidly with the sediment size.

Moderate variations in the actual sediment concentration and in the temperature of the suspension were found to have no perceptible effect upon the results. Data from two series of samples whose mean concentrations were 1250 and 2150 p.p.m. and two series of samples collected at temperatures of 67° and 90° F., are presented in Fig. 10. There is no consistent variation in these data which can be attributed to variations in the temperature or the sediment concentration.

15. <u>Effect of small deviations from normal nozzle orientation on errors in sediment concentration</u>--The direction of orientation of a sampler nozzle with respect to the direction of the stream current might vary considerably during sampling. Any deviation of a sampler nozzle from facing directly into the stream flow represents a deviation from the specified standard sampling conditions. To evaluate the effects of small deviations, tests were made with the standard nozzle set at angles of 10°, 20°, and 30° from the normal position. Each test consisted of a series of samples collected at various intake rates, and showed the effect of deviations from normal position as well as of deviations from normal intake rate. Results of these tests are shown in Fig. 15 and the corresponding test with the standard nozzle in the normal position has been replotted thereon for comparison. The results of the 10° test have been

omitted from the graph because they did not differ from the basic test.

Fig. 15 shows that with a deviation of 20° from the normal direction, other conditions at the intake being the same, the sampler nozzle tends to collect samples of lower sediment concentration than those collected at the normal position, and at an angle of 30° this tendency becomes quite appreciable. The effect of deviations in orientation of a nozzle from the normal direction is small in comparison to the errors due to deviations from normal intake rates.

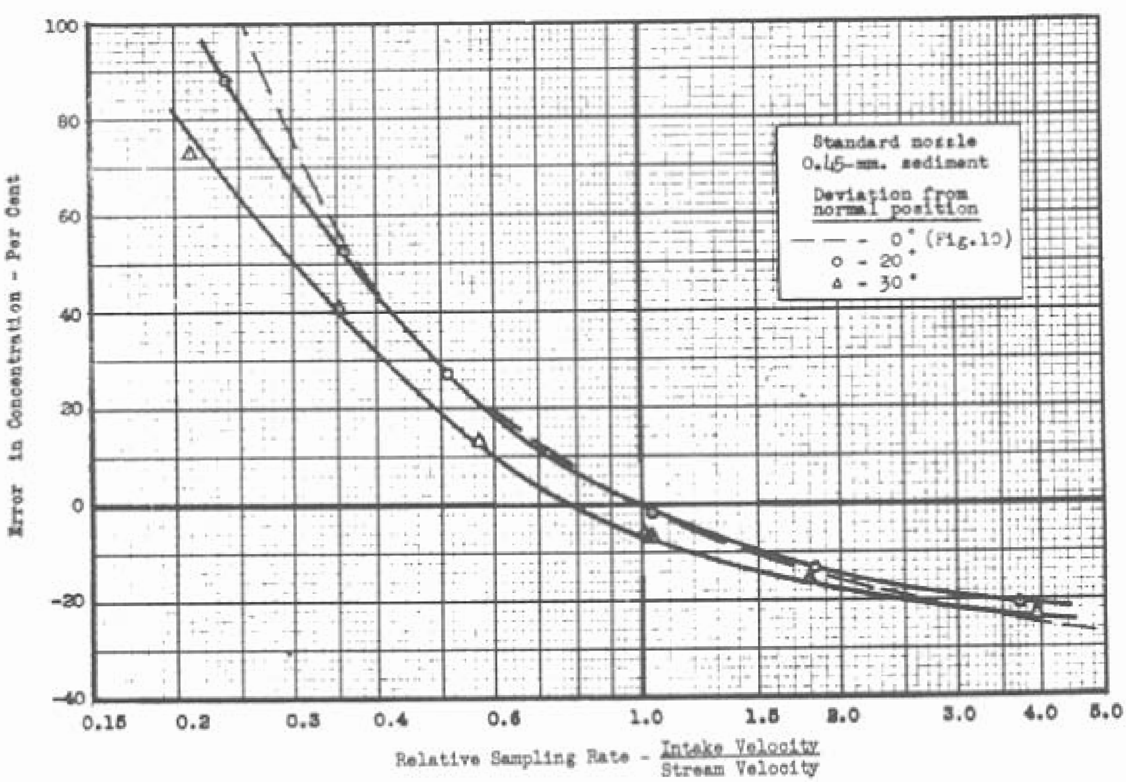


Fig. 15--Effect of small deviations from normal nozzle orientation on errors in sediment concentration.

16. Effect of size of nozzle mouth on errors in sediment concentration--Theoretically, the standard sampling conditions, specified in

Section 10, are independent of the area of the nozzle mouth. Samples collected under normal conditions should be volumetrically proportional to the area of the nozzle mouth but identical in sediment concentration. It may be reasoned further, that th- magnitude of error in a sample due to deviation from the normal intake rate would bear a relation to the area of the mouth of the nozzle. To investigate this, tests were made with two standard nozzles, whose entrances were 0.375 in. and 0.15 in. in diameter, for direct comparison with tests on the nozzle 0.250 in. in diameter.

Results of the tests on the 0.375-in. and 0.15-in. nozzles, together with the corresponding test on the 0.25-in. nozzle, are shown in Fig. 16. These data indicate that the size of the mouth of a nozzle has comparatively little effect upon the accuracy of samples collected. Errors in

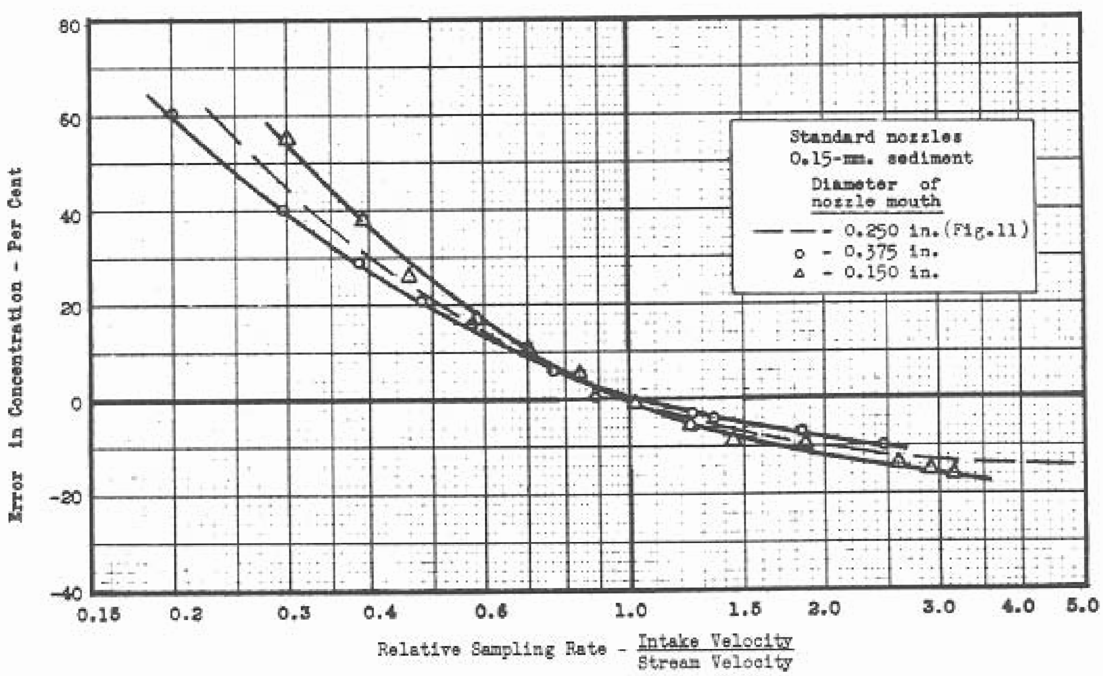


Fig. 16--Effect of nozzle size on errors in sediment concentration.

the sediment concentration of a sample resulting from deviations from the normal sampling rate, are somewhat larger with smaller nozzles, but at the normal sampling rate, the samples collected through nozzles of different sizes were identical in concentration.

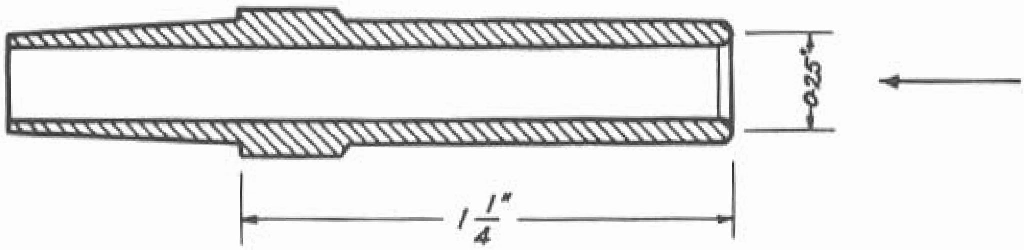
These results from the collection of samples identical in sediment concentration with nozzles of different mouth areas serve to verify the accuracy of the standard sampling conditions.

17. <u>Effect of sampler nose design on errors in sediment concentration</u>--A sampler, as does any stationary object in a flowing stream, influences the flow pattern of the suspension approaching it, and thereby tends to affect the filament collected as a sample.

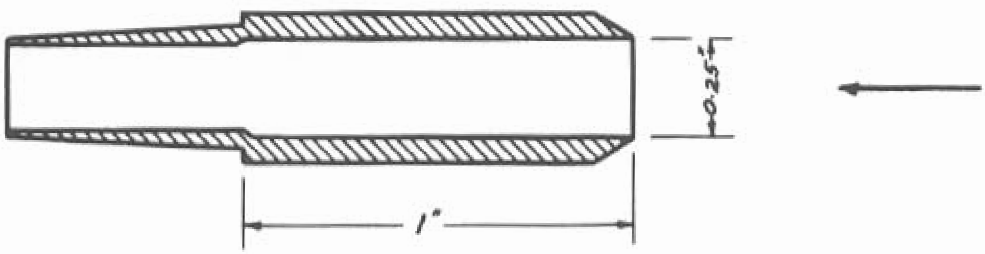
Tests were made with sampler nozzles modified in various ways from the standard design to evaluate the effect of nozzle shape upon the samples collected. These test nozzles, all of which were faced directly into the flow so as to be comparable to a standard nozzle in the normal position, consisted of:

> <u>a</u>. Nozzles modified at the mouth, with edge bluntly rounded, beveled on outside, and beveled on inside as illustrated by Fig. 17 <u>a</u>, <u>b</u>, and <u>c</u>, respectively.
>
> <u>b</u>. Intake simulating a blunt sampler nose with sharp edged mouth, beveled mouth, nozzle extensions in front of the nose 1/2 in., 1/4 in., and 1/8 in. long as illustrated by Fig. 21 <u>a</u>, <u>b</u>, <u>c</u>, <u>d</u>, and <u>e</u>, respectively.
>
> <u>c</u>. An exact replica of the nose of the Rock Island time-integrating sampler, shown in Fig. 66 of Report No. 1, and this replica with a nozzle extension 1 in. long in front of the nose as illustrated by Fig. 23 <u>a</u> and <u>b</u>, respectively.

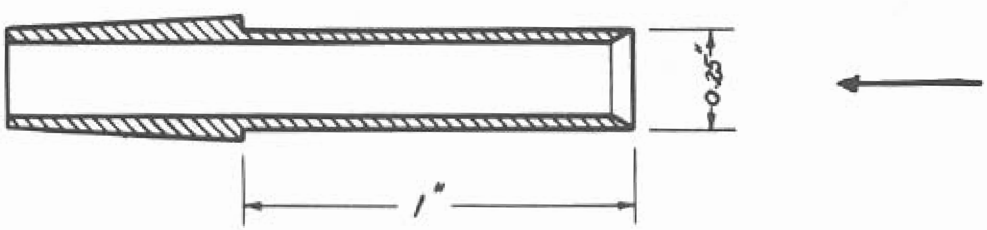
Figs. 18, 19, and 20 show the results of the tests on the three nozzles which were modified only at the mouth. The nozzle with rounded edge shows an appreciable decrease in the magnitude of the errors due to



a. Rounded edge.



b. Beveled outside.



c. Beveled inside.

Fig. 17 - Nozzles modified at mouth from standard design.

FIG. 17

deviations from the normal sampling rate, and when operated at the normal rate, collected samples identical with the standard. The data show that there is a negligible difference in the action of the nozzles, whether beveled on the inside or outside or on both sides, as in the case of the standard nozzle. A nozzle beveled on the outside tends to collect slightly more sediment than a standard nozzle under the same relative intake rates, while the nozzle beveled on the inside tends to collect slightly less.

The sampling rate was computed, for each of the beveled nozzles, using as the effective area of the mouth the area defined by the sharp edge. In the case of the nozzle with the rounded edge, the effective area was based on a mean of outside and inside diameters. If the area of this nozzle were considered to be the inside area, and computation of intake velocity were made accordingly, the curve shown on Fig. 18 would

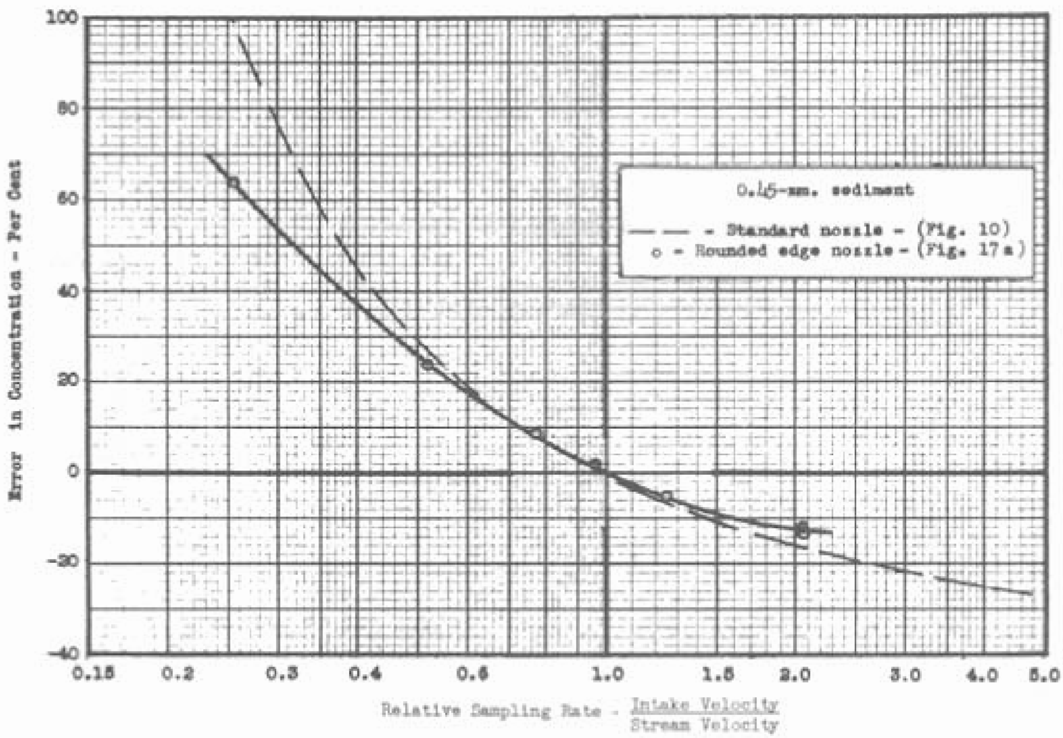


Fig. 18--Effect of round edge nozzle mouth on errors in sediment concentration.

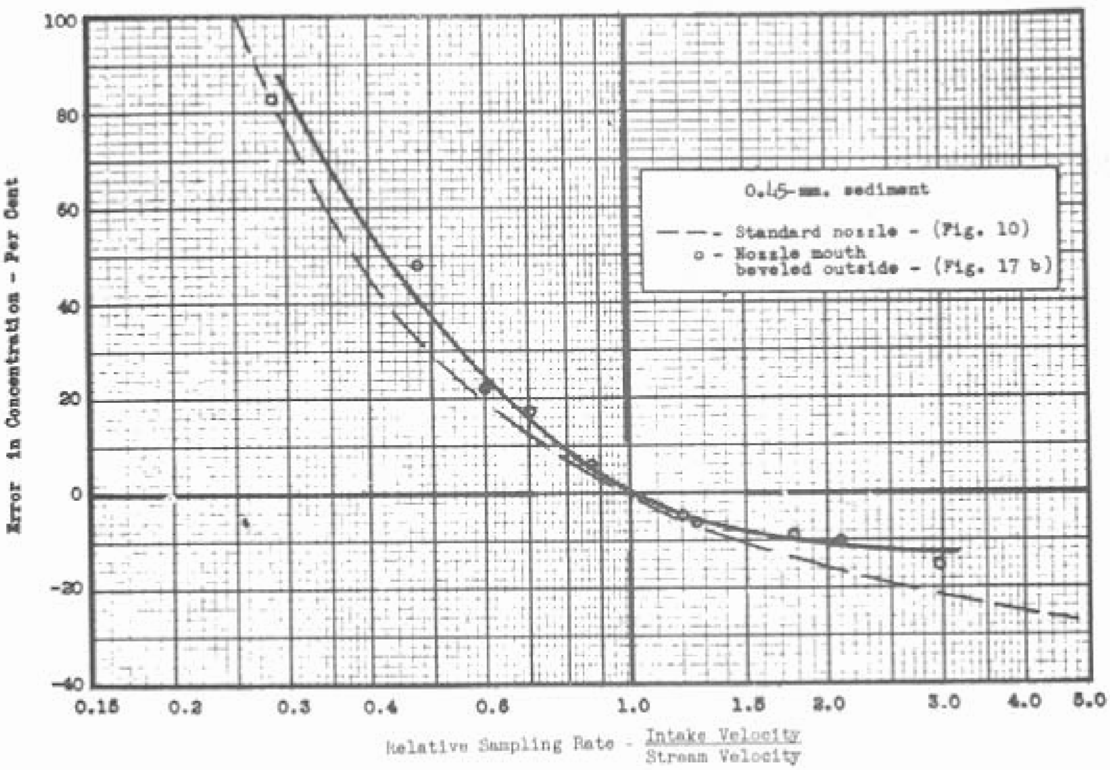


Fig. 19 - Effect of outside beveled nozzle mouth on errors in sediment concentration.

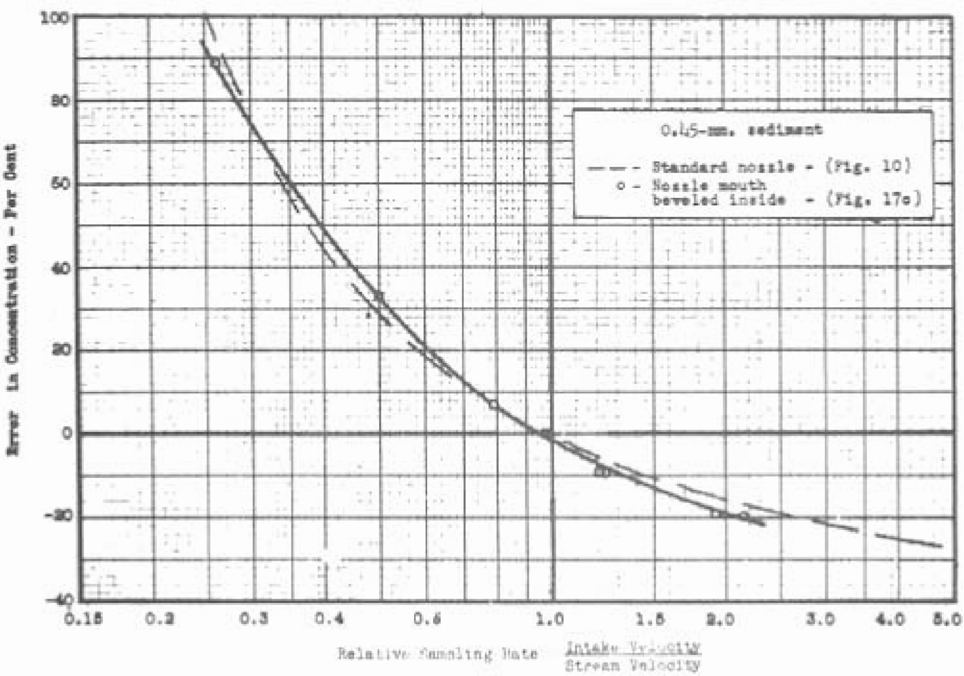
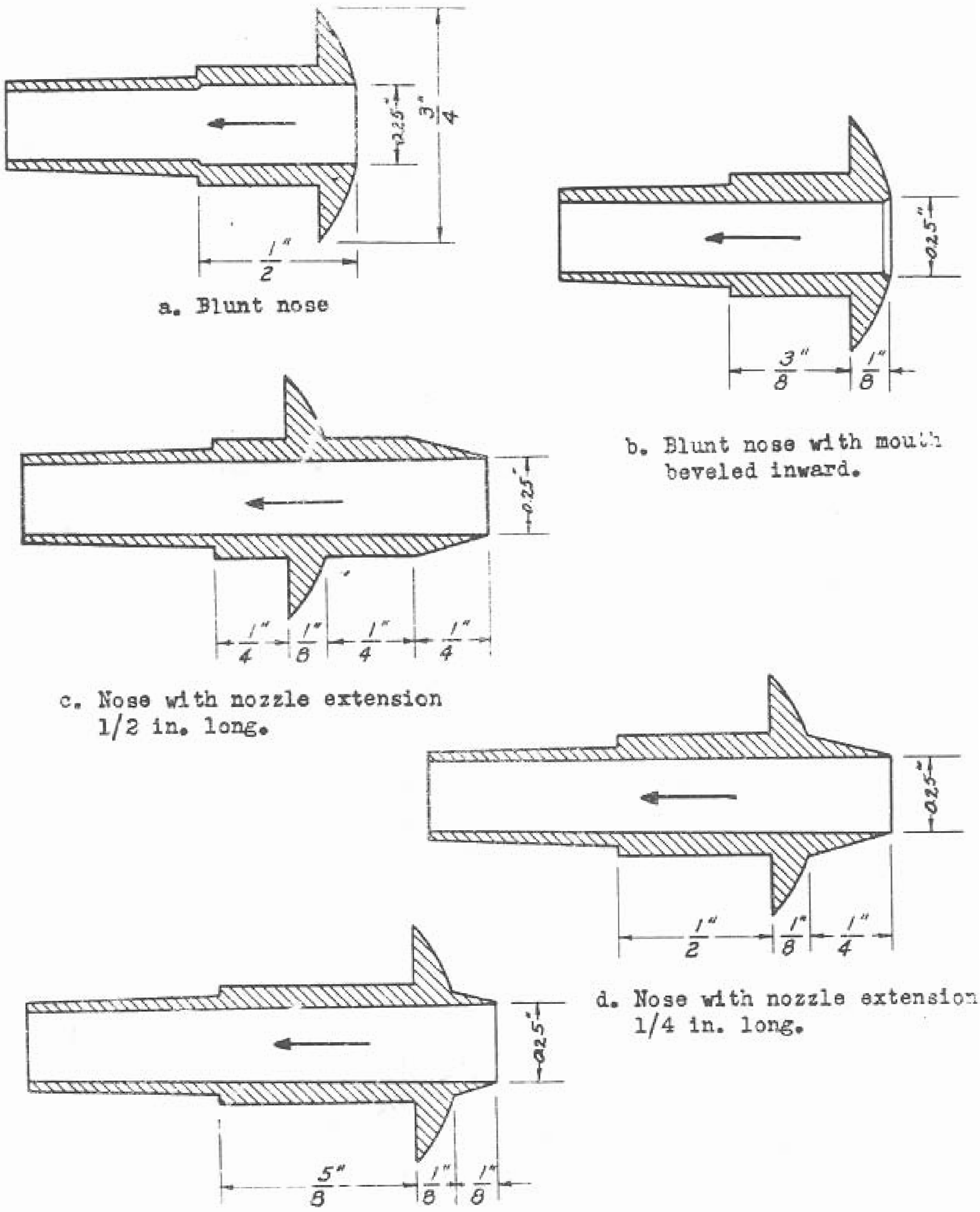


Fig. 20 - Effect of inside beveled nozzle mouth on errors in sediment concentration.



a. Blunt nose

b. Blunt nose with mouth beveled inward.

c. Nose with nozzle extension 1/2 in. long.

d. Nose with nozzle extension 1/4 in. long.

e. Nose with nozzle extension 1/8 in. long.

Fig. 21 - Blunt nose sampler intakes.

be shifted along the horizontal axis, and would show an excess of sediment collected in the samples even at the normal intake velocity, and consequently an increase in the magnitude of errors for the slower rates.

Results obtained with the blunt nose sampler intakes are shown by Fig. 22. From these data it is seen that all of the nozzles shown in Fig. 21 act in a manner similar to that of the standard nozzle. The sampling rate affected the accuracy of the samples more than do small deviations from the standard nozzle shape. It can be reasoned that the curves shown for each respective intake would be affected by the variables of sediment size, stream velocity, and size of mouth in a way similar to the curves obtained with standard nozzles.

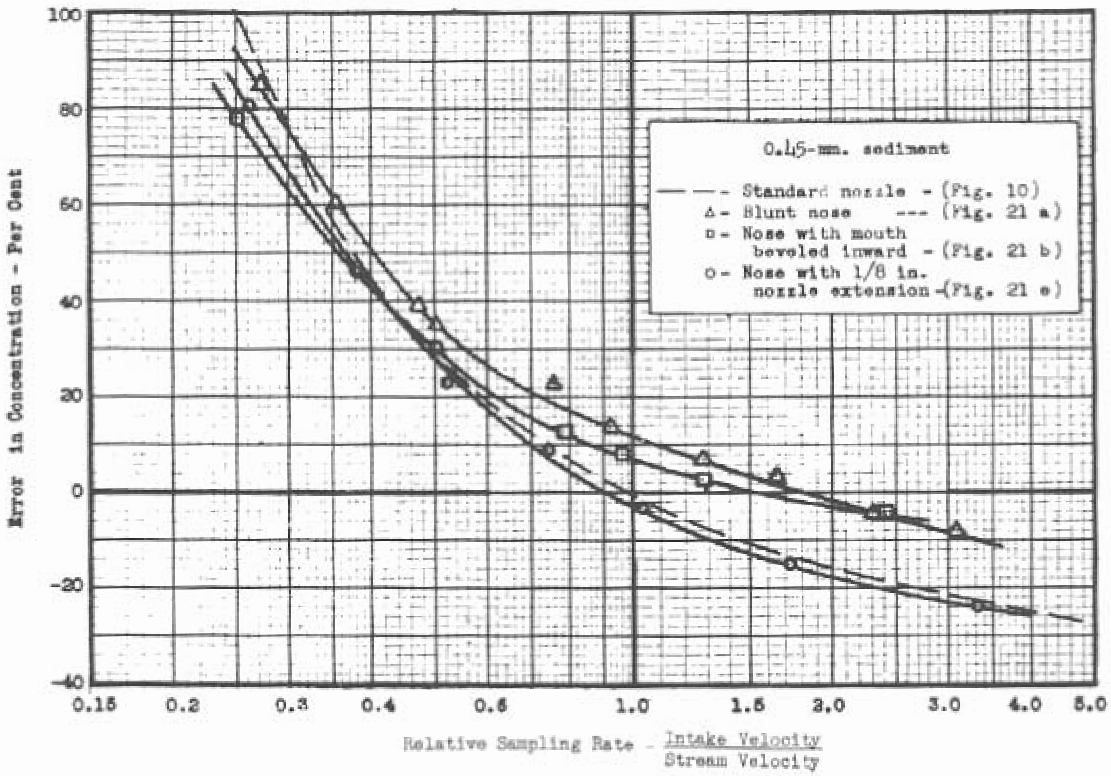


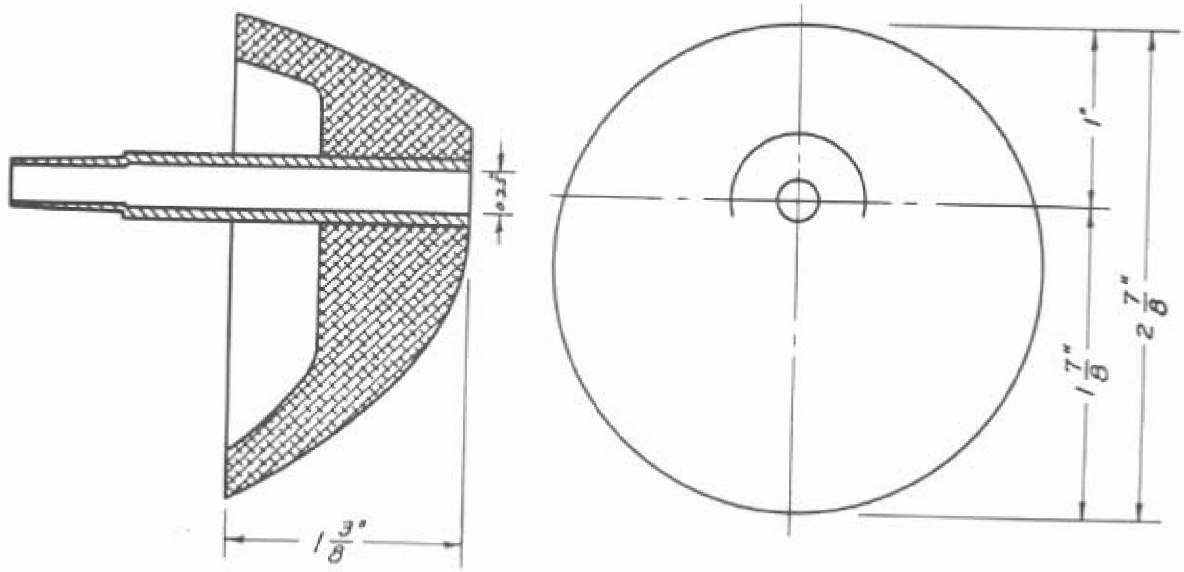
Fig. 22--Effect of blunt nose sampler intakes on errors in sediment concentration.

The blunt nose intake with sharp edged mouth and without nozzle extensions collected 12 per cent excess of sediment at the normal intake rate. At lower sampling rates, it approached the action of the standard nozzle. The action of the blunt nose intake was improved slightly by beveling the edge of the mouth in which case only 6 per cent excess of sediment was collected at the normal intake rate. At low intake rates this nozzle collected samples slightly less in error than did the standard, but the difference is unimportant in comparison to the error caused by the slow rate.

Nozzle extensions of 1/2 and 1/4 in. in front of the nose gave results which were the same as those obtained with a standard nozzle. Results of these tests were not plotted because they were so nearly the same as those of the standard nozzle. The 1/8-in. nozzle extension was not sufficient to obviate the effect of the blunt nose, but it changed its action so that, at the normal rate, instead of collecting an excess of sediment the nozzle collected insufficient sediment.

The actual lengths of these extensions are meaningless unless compared dimensionally with the size of the mouth, and the size and shape of the nose. As sufficient data were not collected to allow a reliable dimensionless correlation of these factors, conclusions as to the effective length of nozzle extensions must be avoided.

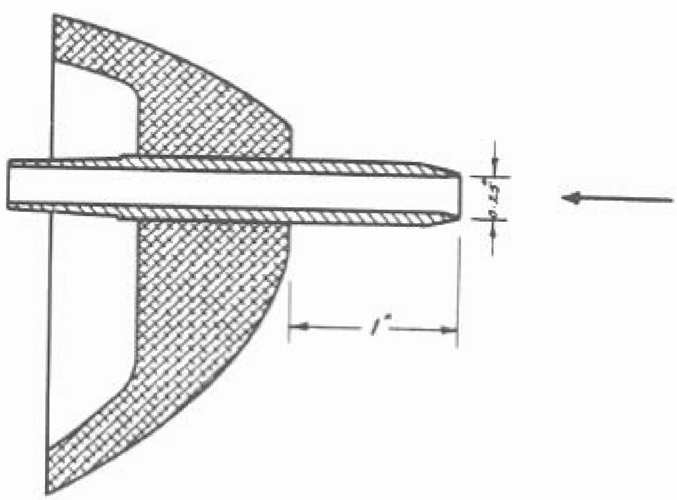
Fig. 24 shows the results of tests with the replica of the nose of the Rock Island sampler, with and without an extension of the nozzle as illustrated in Fig. 23. The data show that a sampler of this type collects a considerable excess of sediment, even at a normal sampling rate. With the nozzle extended 1.0 in. in front of the nose of the



Section

Front view

a. Replica of nose.



b. Nose with nozzle extension 1 in. long.

Fig. 23 - Replica of Rock Island time-integrating sampler nose.

sampler, the effect of the nose upon the suspension was relatively negligible. Observations were made to verify the validity of these data, and it was concluded that, although the presence of so large a nozzle in the sampling section disturbed the distribution of sediment, in general, the results stated above were correct.

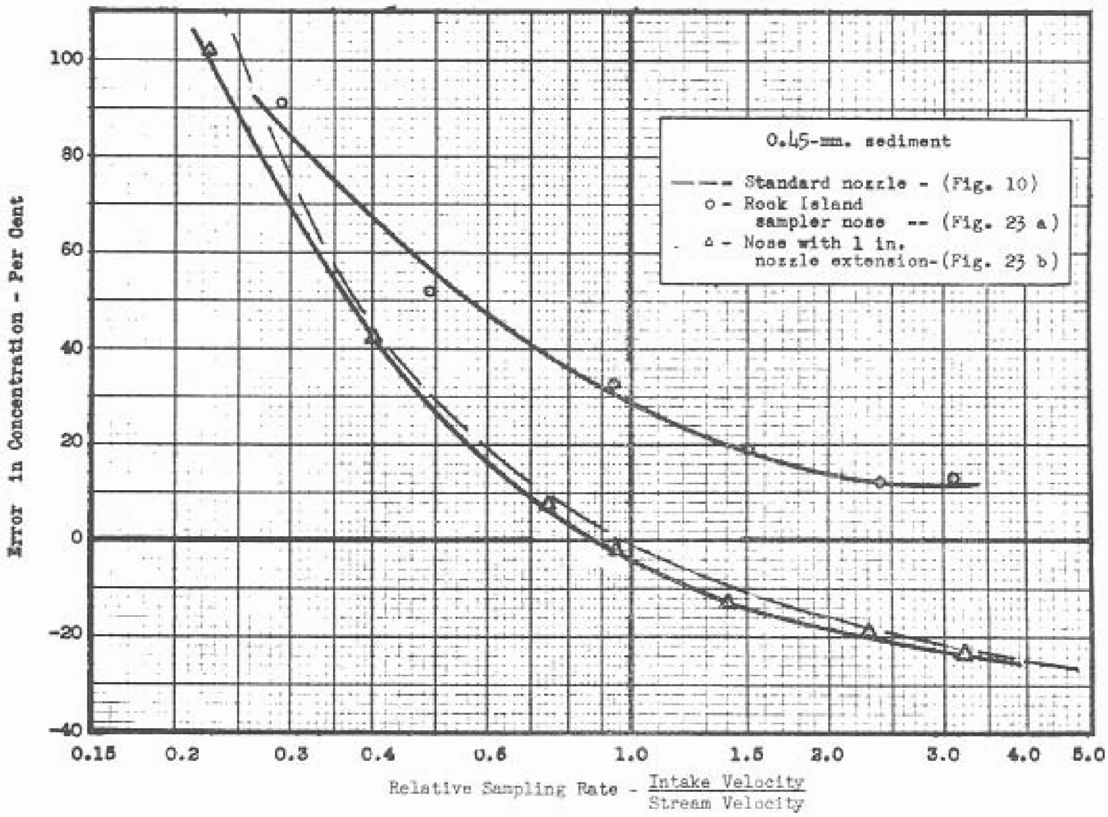


Fig. 24--Effect of Rock Island sampler nose on errors in sediment concentration.

It is apparent from these data that, in the use of any nozzle facing into the stream, the sampling rate is the primary factor to be controlled. Furthermore, the intake to the sampler should be extended upstream beyond the point where the streamlines are affected by any blunt section of the sampler.

18. <u>Effect of flap valves at sampler intakes</u>--Flap valves, commonly placed above the mouths of instantaneous, horizontal trap samplers, undoubtedly cause disturbances in the water-sediment filament approaching the mouth of the sampler. To evaluate the general magnitude of the effect of such conditions upon the regular operation of a sampler, tests were made with models of flap valves in the open position attached to the standard nozzle and protruding over and in front of the mouth of the nozzle. Although these tests did not duplicate the operation of instantaneous samplers, the results are believed to be representative of results obtained with such samplers, inasmuch as the phenomenon involved is fundamentally the same.

Flap valves, as illustrated by Fig. 25, were tested in each of three positions, namely:

<u>a</u>. Valve extended horizontally from top of nozzle mouth.

<u>b</u>. Valve deflected upward from the top of the nozzle mouth at an angle of 30° with the horizontal.

<u>c</u>. Valve deflected downward from the top of the nozzle at an angle of 30° with the horizontal.

Each test consisted of a series of samples collected at different sampling rates.

Results of these tests are shown in Fig. 26. The curve from the basic standard sampler in the normal position without flap valves is repeated for comparison. These data show that the flap valve in the horizontal position had relatively little effect on the accuracy of the samples collected through a standard nozzle. The flap valve inclined upward tended to deflect an excess of sediment into the nozzle, and the flap valve inclined downward, obstructing the flow directly into the nozzle,

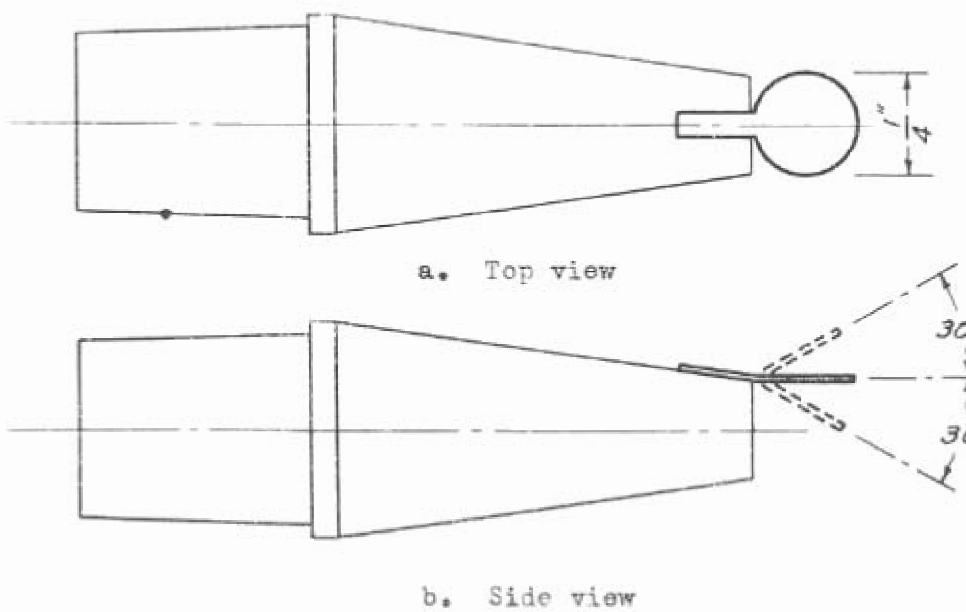


Fig. 25 - Flap valve in alternate positions at mouth of standard nozzle.

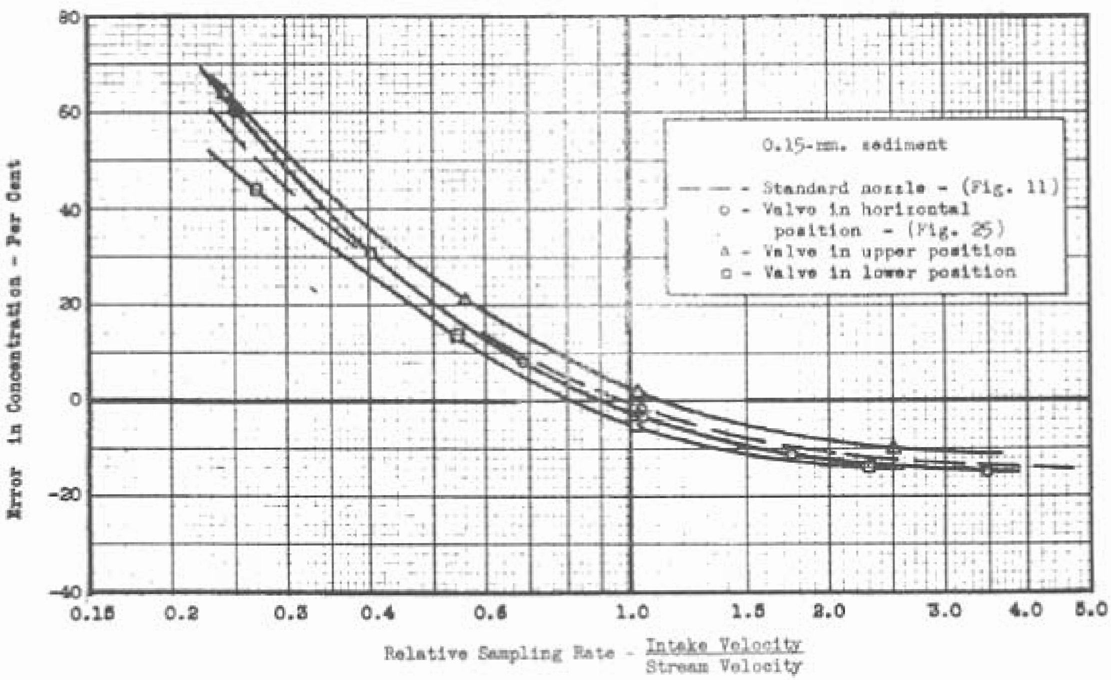


Fig. 26 - Effect of flap valve at mouth of nozzle on errors in sediment concentration.

had the opposite effect. Although the effects of these appurtenances were small in comparison to the magnitude of the errors which result from an incorrect sampling rate, they should be avoided if possible where highly accurate sampling is desired.

19. Errors in sediment concentration of samples collected with nozzles in vertical position--Several nozzles were oriented in the test conduit to simulate sampler entrance conditions in the common slow filling or bottle type samplers and to some extent in vertical trap samplers. For photographs and descriptions of these samplers, reference is made to Report No. 1 of the study of "Methods Used in Measurement and Analysis of Sediment Loads in Streams," Sections 47 to 53 for vertical trap samplers and Sections 69 to 81, 89 and 90, for the slow filling samplers. Samplers of these types have mouths which do not face into the stream flow and a sample entering them must undergo a 90° change of direction, and consequently there is a tendency for segregation and loss of sediment to take place.

Several of the samplers referred to are constructed with separate air exhausts so that the inflow of the sample is steady and continuous. In those not so equipped the flow pattern of an entering sample is disturbed by the spasmodic escape of air. Such disturbance, or bubbling action, and its effect upon the sampled filament, was neglected in these tests. The various nozzles oriented in the vertical position were tested with the same procedure as described in Section 11, each test consisting of a series of samples collected at different sampling rates. The sampling rates were expressed, as in the tests with nozzles facing into the stream, by the ratio of the velocity in the mouth, intake velocity, to the stream velocity. Although the physical significance of such a ratio is not clearly defined for these conditions, it is a convenient factor to use in presenting the results. The entrance conditions as established by the variable factors of stream velocity, sediment size, and physical features of the sampler such as size, shape, and size of mouth, were varied for the different tests to allow evaluation of the effect of each factor separately.

The nozzles consisted of the following:

_a_. Standard shaped nozzles, in each of two mouth sizes, placed in the vertical position as illustrated by Fig. 27.

_b_. Intakes consisting of orifices, 0.150 and 0.250 in. in diameter, in the top surface of a thin horizontal plate as illustrated by Fig. 31.

_c_. Intake consisting of an orifice, 0.250 in. in diameter in the top surface of a mushroom disk as illustrated by Fig. 35.

These nozzles were designed to approximately simulate the entrance conditions of actual samplers and are not exact replicas of any one sampler.

Tests with the standard nozzles in the vertical position were made as follows:

_a_. Four tests, using 0.45-mm., 0.15-mm., 0.06-mm., and 0.01-mm. sediment, respectively, with 0.25-in. nozzle and stream velocity of 5 ft./sec.

_b_. One test, using 0.15-mm. sediment, with 0.25-in. nozzle and 3 ft./sec. stream velocity for comparison with similar test, above, at 5 ft./sec. stream velocity to show the effect of this factor.

_c_. One test, using 0.45-mm. sediment, with 0.15 in. nozzle and 5 ft./sec. stream velocity for comparison with similar test, above, with 0.25-in. nozzle to show the effect of nozzle size.

Results of the four tests with various sizes of sediment are presented in Fig. 28. Large errors in the sediment content of a sample resulted from the abrupt change in direction of flow at the mouth of this sampler. The errors, all negative, demonstrate that the sediment was segregated from the sampled filament of water as it turned to enter the sampler. The sediment particles passed on and did not enter the mouth of the sampler. The factor which affected the magnitude of the error most was the sediment sizes as shown by the four curves in Fig. 28. At any sampling rate, the error increased with sediment size up to the 0.15-mm. sediment but there was little difference in the results obtained with the 0.15-mm. and 0.45-mm. sediments. The error varied greatly with the sampling rate; from a very high value at low rates to a smaller and nearly constant value at normal and faster rates. With the smaller sizes of sediment, the error varied less markedly with the sampling rate but was still negative and of appreciable magnitude.

Results of two comparable tests, differing only in stream velocity are presented in Fig. 29 to show the effect of this factor upon the magnitude of the errors. The error was larger with the faster stream velocity, but the effect of stream velocity was small in comparison to the magnitude of the total error caused by the orientation of the sampler.

Results of two comparable tests with different sizes of sampler mouths but with all other conditions the same are shown in Fig. 30. The magnitude of the error varied inversely, and to an appreciable extent, with the size of opening, larger errors resulting with the smaller nozzle.

Tests with intakes consisting of an orifice in a flat horizontal plate, shown in Fig. 31, were made as follows:

a. Three tests, using 0.45-mm., 0.15-mm., and 0.06-mm. sediment, with intake 0.250-in. diameter and stream velocity of 5 ft./sec.

b. Two tests, with stream velocities of 4 ft./sec. and 3 ft./sec., with intake 0.250-in. diameter and 0.15-mm. sediment for comparison with similar test above at 5 ft./sec. to show the effect of stream velocity.

c. One test with intake 0.150-in. diameter and with 0.15-mm. sediment and 5 ft./sec. stream velocity for comparison with the similar test above with intake 0.25-in. diameter to show the effect of mouth size.

Results of the three tests with different sizes of sediment are shown in Fig. 32. As in the tests on the standard nozzle in the vertical position, the error in sediment content of a sample was negative, demonstrating the loss of sediment from the sampled filament as it turned to enter the mouth of the sampler. The magnitude of the error, as in all previous tests, decreased with smaller sizes of sediment, but this tendency was less evident with the two large sizes of sediment, 0.15 mm. and 0.45 mm., respectively. For the particular conditions of these three tests, the sampling rate had little effect upon the magnitude of error. The three tests at different stream velocities presented in Fig. 33, indicated that as the stream velocity decreased the proportion of sediment entering the sampler increased, resulting in an excess of sediment being collected when the stream velocity and relative sampling rate were low.

The two tests in which size was the variable, presented in Fig. 34, indicated that both the magnitude of error and the relative effect of the sampling rate on the error in sample concentration, were dependent on the mouth size.

From these tests with flat plate nozzles, it was concluded that the entrance conditions and their effect upon a sample are too complex for thorough analysis without more exhaustive tests. It can be reasoned that there are two general phenomena affecting the relative behavior of the sediment and water passing and entering a sampler of this type. The one already discussed is that the sediment, being of greater density than the water, tends by its greater inertia to resist the sharp directional change and passes by the sampler mouth. The second arises from the effect of the flat plate upon the flow characteristics. In the suspension adjacent to the plate, boundary conditions are set up which are similar to those along the boundaries of a conduit. Turbulence is decreased in this layer, resulting in the settling out of sediment along the surface of the plate and the movement of the sediment in higher than normal concentrations until it drops into the mouth of the sampler as excess sediment. These two phenomena are opposite in nature and effect; the former predominating at higher stream velocities, and the latter at lower velocities. A condition may be considered, with a suspension of sediment varying widely in particle sizes, in which samples would contain insufficient quantities of small sizes of the sediment and an excess of the large sizes.

Results of the single test with the mushroom shaped sampler intake, shown in Fig. 36, indicate that its action was similar to that of the other vertical intakes. Exhaustive tests were not made with this nozzle, as there was no indication of advantages to be gained in a sampler designed along these lines. It seemed probable that a thorough analysis of the intake conditions into this nozzle would be complicated by the same variable factors and phenomena affecting the flat plate nozzle.

20. <u>Errors in sediment concentration of samples collected through sampler intake horizontal and normal to flow</u>--It was pointed out in

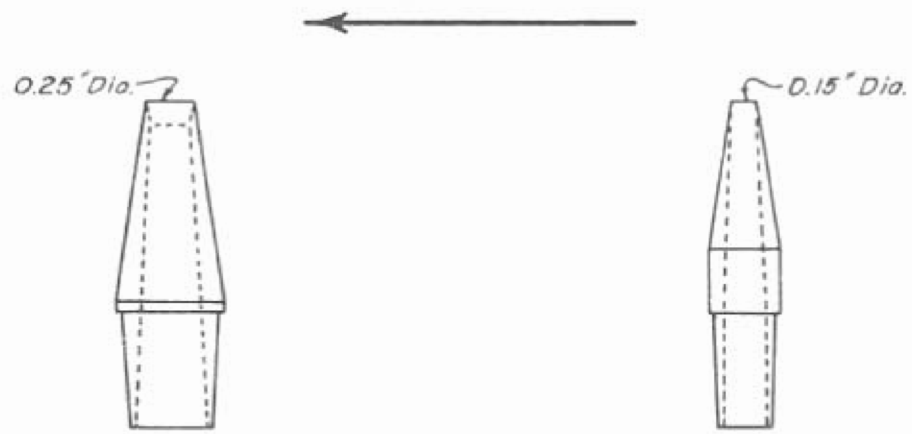


Fig. 27 - Standard shaped nozzles in vertical position.

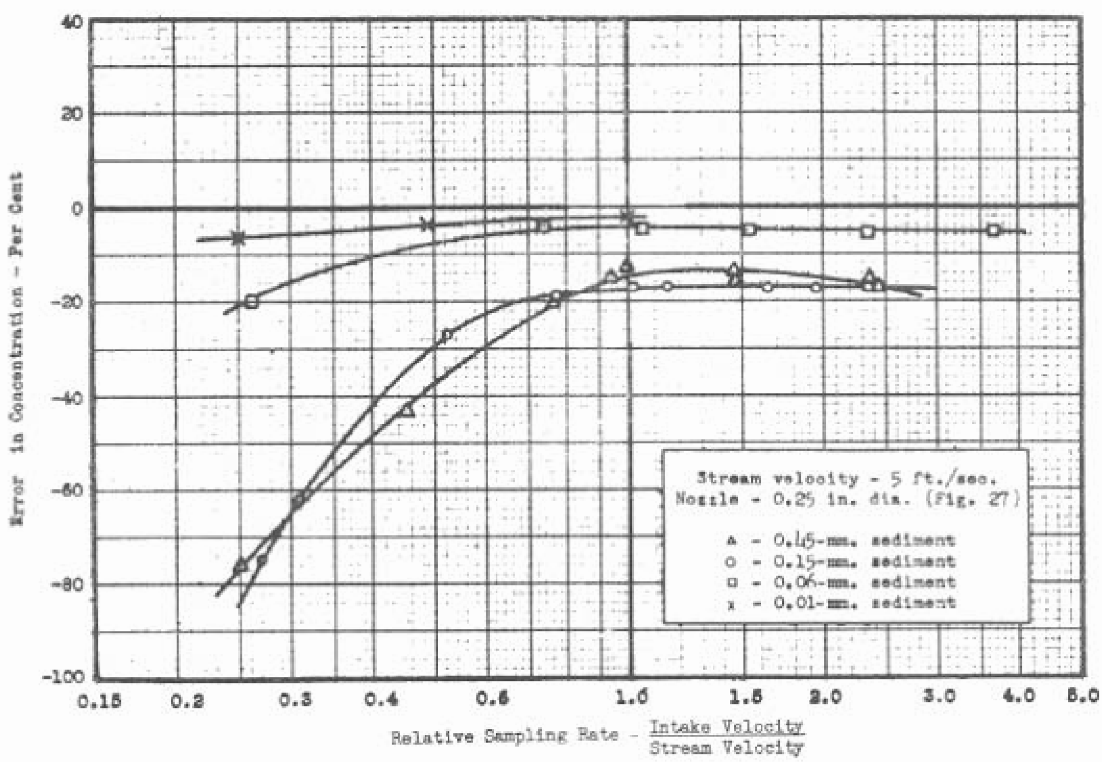


Fig. 28 - Effect of sampling rate and sediment size on errors in sediment concentration with standard nozzle in vertical position.

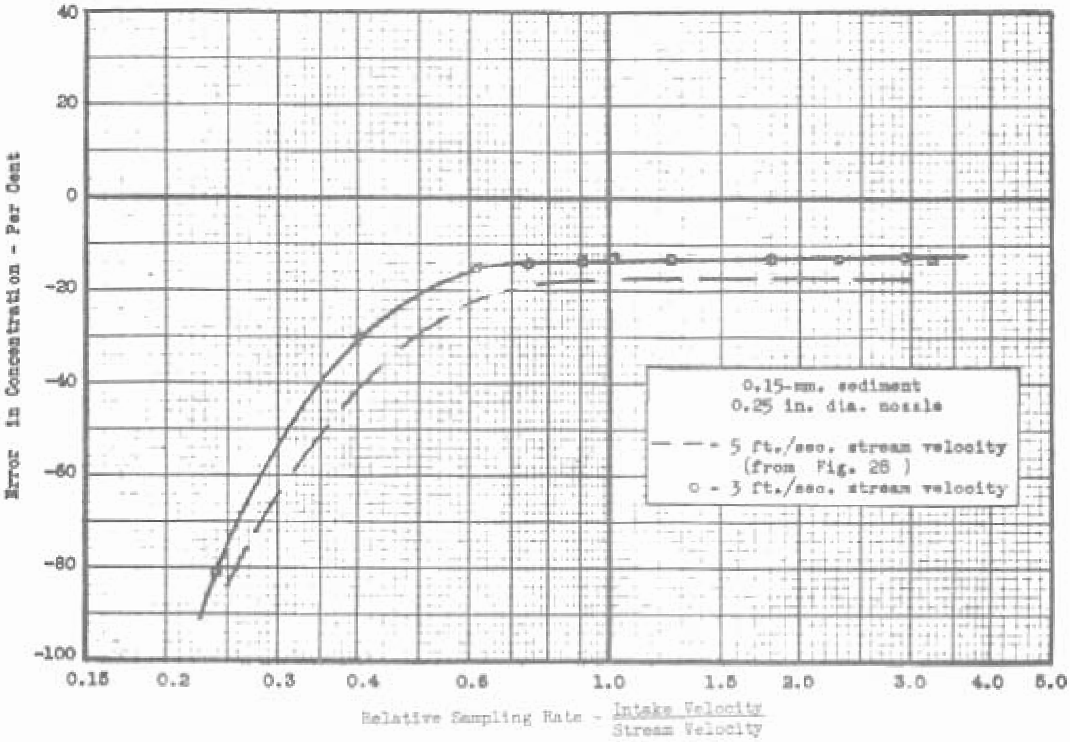


Fig. 29 - Effect of stream velocity on errors in sediment concentration with standard nozzle in vertical position.

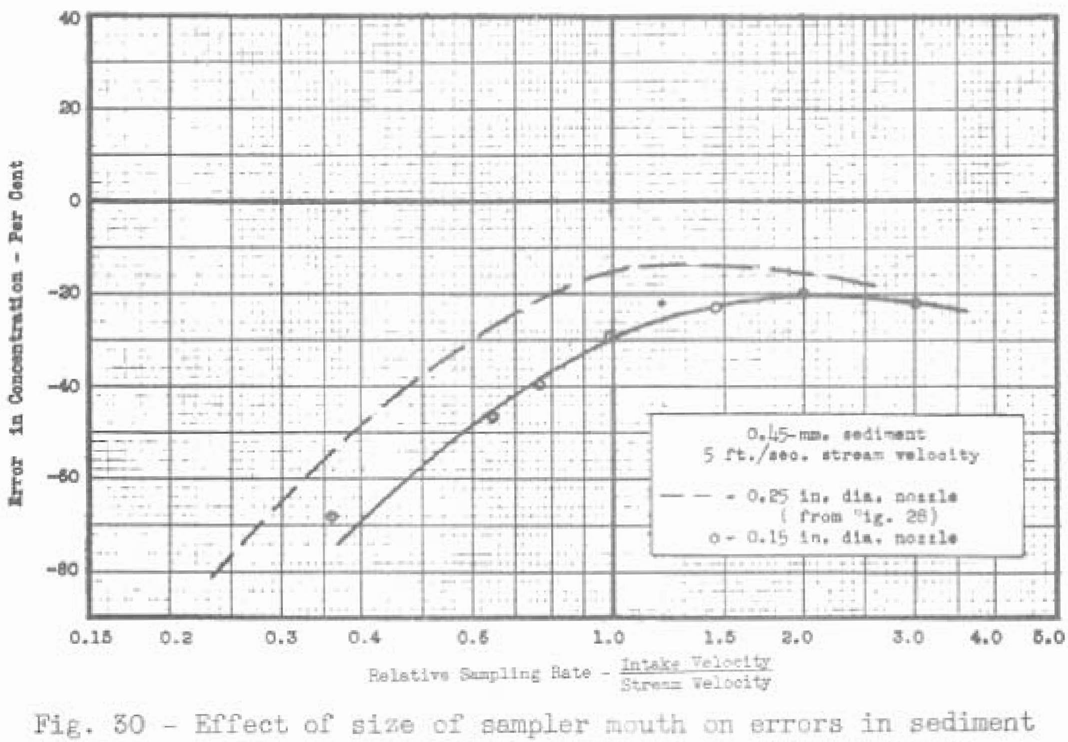


Fig. 30 - Effect of size of sampler mouth on errors in sediment concentration with standard nozzle in vertical position.

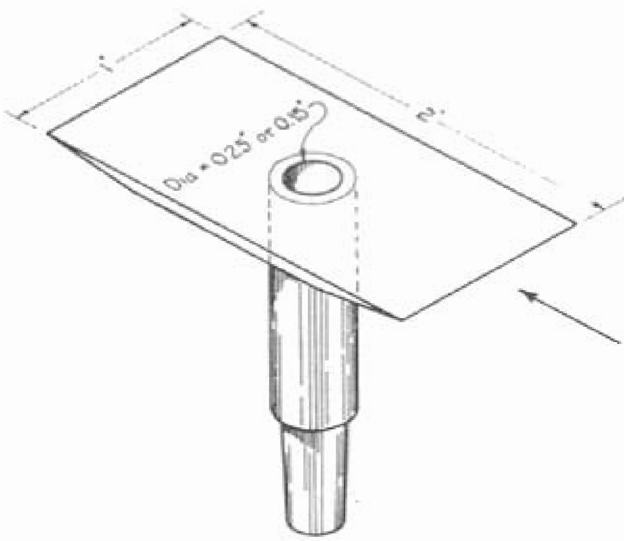


Fig. 31 - Sampler intake in vertical position; orifice in flat plate.

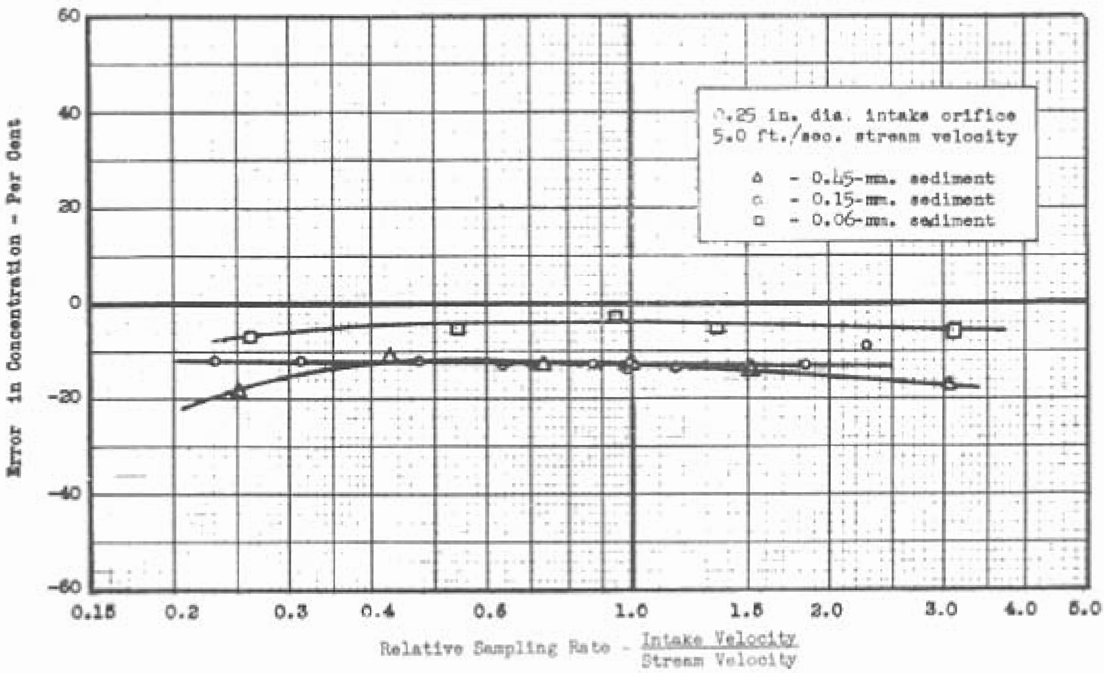


Fig. 32 - Effect of sampling rate and sediment size on errors in sediment concentration with flat plate intake in vertical position.

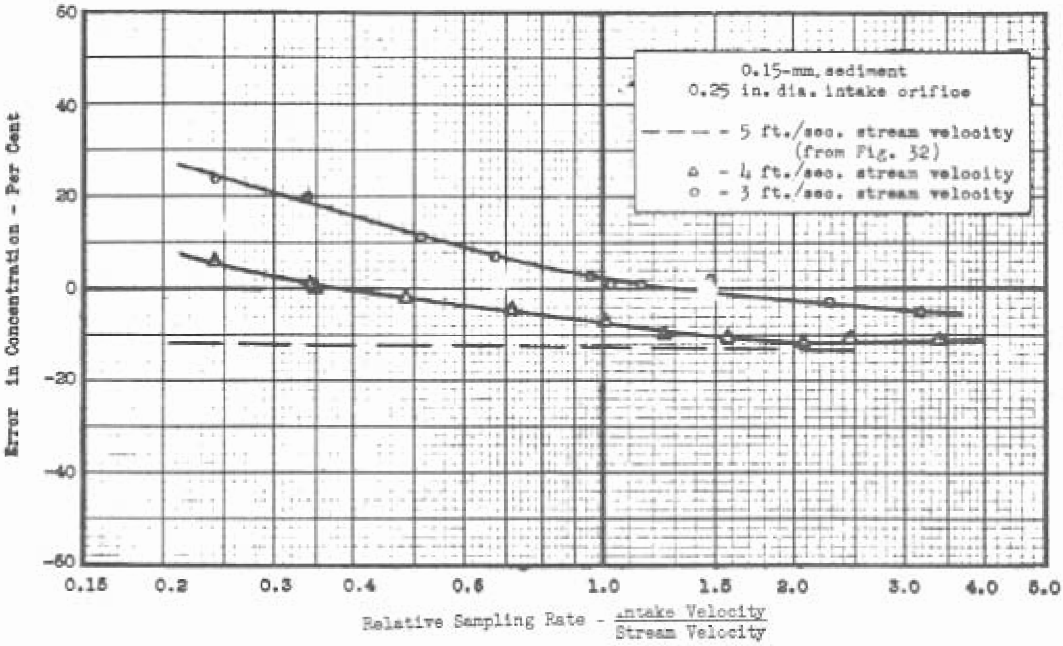


Fig. 33 - Effect of stream velocity on errors in sediment concentration with flat plate intake in vertical position.

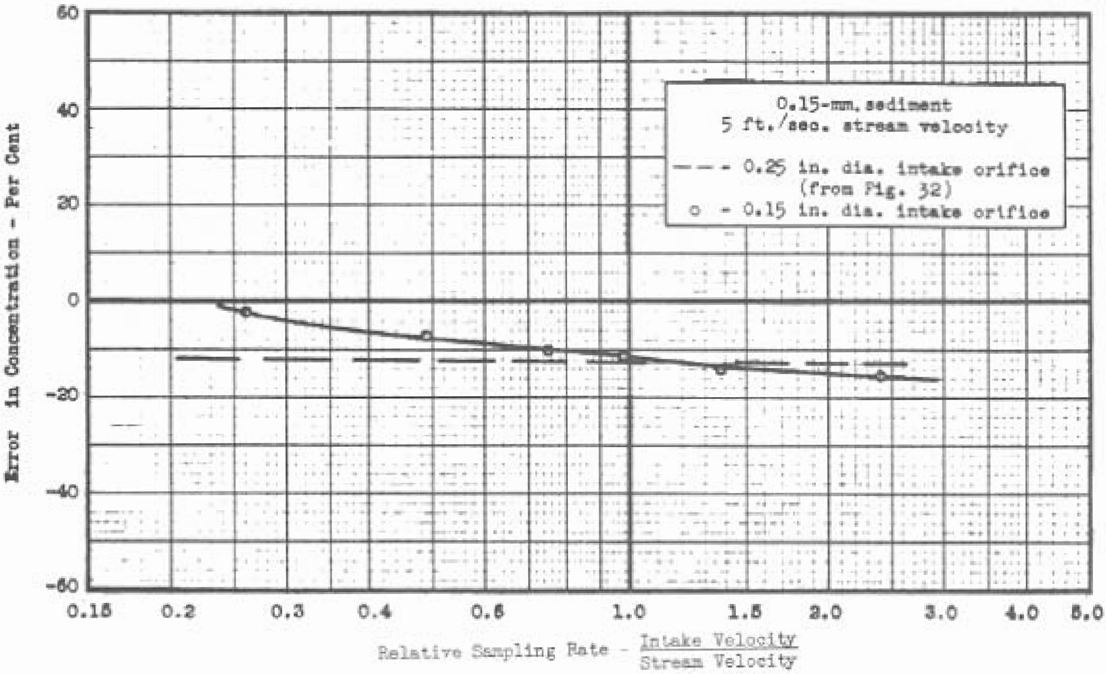


Fig. 34 - Effect of mouth size on errors in sediment concentration with flat plate intake in vertical position.

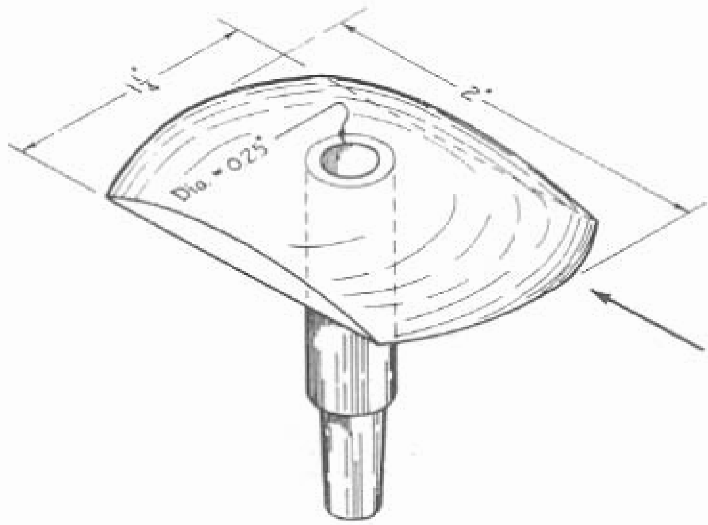


Fig. 35 - Mushroom shaped sampler intake in vertical position.

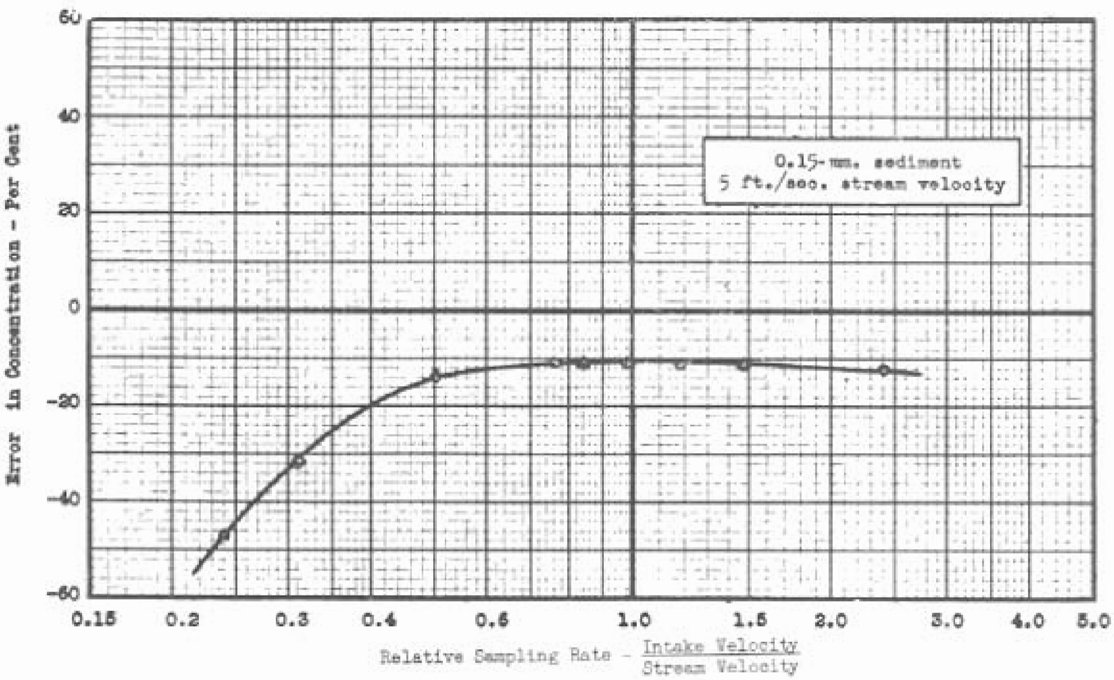


Fig. 36 - Effect of sampling rate on errors in sediment concentration with mushroom shaped intake in vertical position.

Section 19, in the discussion of results of tests on flat plate nozzles with the plate horizontal, that two fundamental factors probably influenced the behavior of a water-sediment suspension entering such a sampler. The factors are:

a. Sediment resisting the right-angle change of direction of flow and passing the sampler intake.

b. Sediment settling and moving along the surface of the plate in higher than normal concentration to drop into the sampler mouth as an excess in the sample.

The effect of the first of these factors should be nearly the same whether the flat plate is horizontal or vertical, so long as the plate paralleled the stream flow, since the directional change of flow would be the same in either case. The second factor, however, should have no effect on a flat plate sampler intake oriented horizontal and normal to the flow.

To obtain data which would show the validity of the above hypothesis and perhaps permit evaluation of the second factor, when compared with data presented in Section 19, tests were made with the flat plate sampler intake placed in the conduit as illustrated in Fig. 37.

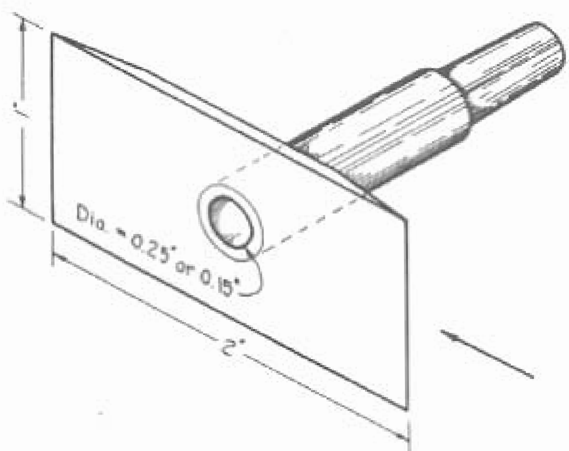


Fig. 37--Flat plate sampler intake horizontal and normal to flow.

Tests of the flat plate sampler intake horizontal and normal to flow were made as follows:

a. Two tests, using 0.45-mm. and 0.15-mm. sediment, with the 0.15-in. mouth and stream velocity of 5 ft./sec.

b. Two tests with sediment and stream velocity conditions same as above but with the 0.25-in. mouth.

c. One additional test with a stream velocity of 3 ft./sec., 0.15-mm. sediment, and the 0.15-in. mouth.

Results of the four tests described in a and b are shown in Fig. 38. The negative error was large in magnitude and was definitely a function of the sediment size. It varied to some extent with the sampling rate, increasing with decreasing intake velocities. The magnitude of the error was not affected materially by the difference in mouth size.

Results of the two tests at 5 and 3 ft./sec. stream velocity, other factors the same, are shown in Fig. 39. The effect of the stream velocity upon the magnitude of the error was practically negligible and not clearly defined by the data.

A comparison of the curves in Figs. 38 and 39 with similar curves in Figs. 32 and 33, respectively, illustrates the relative effects of the two intake phenomena discussed above. The negative errors discussed in this section were all greater in magnitude for a given set of test conditions than were the errors discussed in Section 19. This fact verifies the analysis presented at the beginning of this section, since, as was noted in Section 19, the two factors thought to affect sample concentration, flat plate intakes oriented vertically, tend to offset each other.

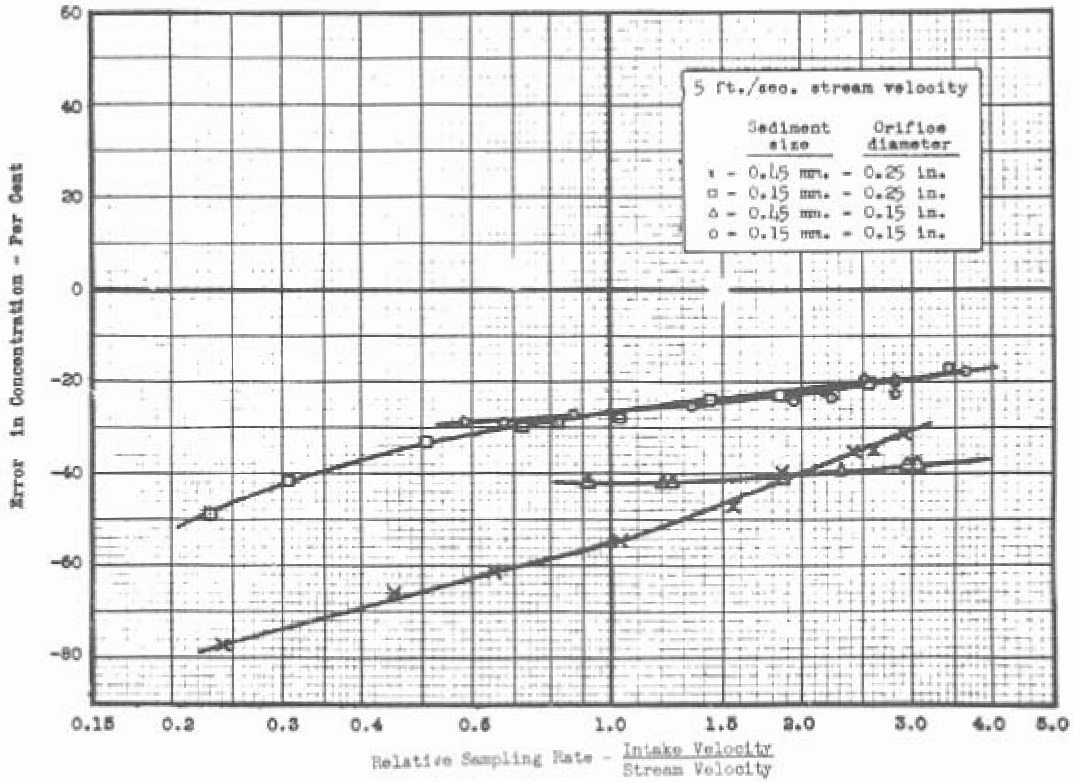


Fig. 38 - Effect of sampling rate, sediment size and mouth diameter on errors in sediment concentration with flat plate intake horizontal and normal to flow.

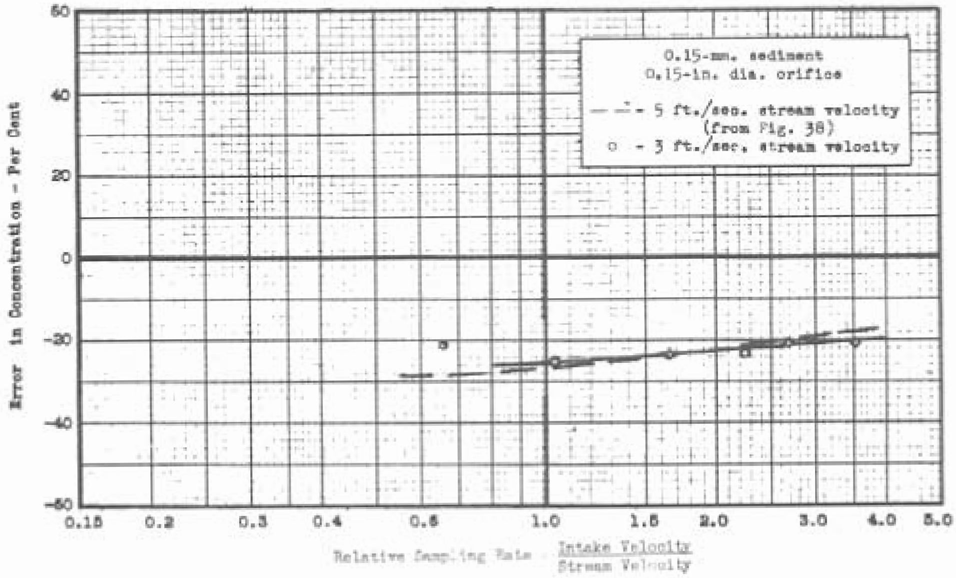


Fig. 39 - Effect of stream velocity on errors in sediment concentration with flat plate intake horizontal and normal to flow.

IV. DEPOSITION OF SEDIMENT IN INSTANTANEOUS HORIZONTAL SAMPLERS

21. Scope of deposition study--The usual form of an instantaneous sampler consists of a horizontal cylinder with a mechanism at each end designed for instant closing. The sampler is usually suspended at any desired point in a stream by means of a cable. The cylinder is maintained in a horizontal position parallel to the stream flow by means of a vane and fins fastened to the sampler in a manner which will not obstruct stream flow. Water flows freely through the cylinder until the operation trips the instant-closing mechanism thereby entrapping a sample. Under certain conditions it has been observed that samples which contain an excess of sediment were collected in such types of samplers. In order to investigate this phenomenon a series of experiments were carried out in the recirculating apparatus described in Section 5 of this report. The scope of the study was very limited, but in order to make the record of the experimental work complete, the following description of the tests and statement of results is presented.

This excessive deposition of sediment probably largely results from a reduction of the vertical velocity components in the filament entering the sampler. Generally, flowing water possesses turbulence with momentary eddies which have upward velocity components of sufficient magnitude to elevate sediment particles in the stream. When the filament enters the mouth of the sampler the vertical components are reduced by the boundaries of the horizontal tube; therefore, some of the larger particles in suspension settle to the bottom of the sampler. The reduction of velocity due to the friction on the inside of the sampling tube would also tend to produce settling. The settling tendency is offset somewhat by the disturbance which occurs at the entrance to the tube, or which may be set up by roughness within the tube. However, under favorable conditions, the coarser sediments may accumulate, and if the sampler is left open for a relatively long time, considerable error in the sediment concentration of the sample may result.

22. Test procedure--These tendencies for sediment to accumulate in a horizontal trap sampler were observed with a transparent cylinder 1-1/4 in. in diameter and 14 in. long, placed in the transparent test section of the conduit. The tests included observations with:

a. The cylinder with smooth unobstructed inside surface, and sharp edged mouth.

b. The cylinder equipped with model flap valves in the open position to cause more turbulent flow in the cylinder.

c. The cylinder equipped further with two brass bands 1/16 in. thick and 1/8 in. wide, spaced along the inside, 3-1/2 and 7 in. from the upstream end.

In each test the flow through the cylinder was observed as the velocity of the circulating suspension was gradually decreased from 5-ft./sec. The velocity allowing sediment to accumulate in the cylinder was maintained for a period of about 20 min. during which time a standard sample was collected to establish the true concentration of the suspension. The flow was then stopped, the cylinder capped and removed and its sample analyzed for comparison with the true sample. Tests were made with the nominal 0.15-mm. diameter sediment.

23. Test results--In each test, as the suspension was passed through the cylinder at the higher velocities, sediment was observed along the

invert of the cylinder in higher than normal concentrations. As the stream velocity was reduced, the sediment moved along in the cylinder in a wave form similar to that of bed load movement. As the stream velocity was still further reduced, it became incapable of moving the sediment along the bottom of the cylinder and there was a distinct, continuous accumulation of sediment in the cylinder. Results of several quantitative measurements of this accumulation are presented in Table 1.

The model flap valves installed at the mouth of the cylinder prevented the accumulation of sediment for a distance of approximately 3 in. downstream from the mouth, but beyond this point the valves had very little effect upon the conditions within the cylinder.

The bands inside the cylinder served to increase the turbulence and greatly decrease the amount of sediment accumulation. Although samples were not obtained with this condition, the phenomenon was observed. No trouble was experienced with sediment being piled up in front of or behind the rings, but that condition might occur with some shapes of obstruction.

Data from the three quantitative tests made with the horizontal cylinders are tabulated below:

TABLE I

TEST DATA--SEDIMENT DEPOSITION IN HORIZONTAL CYLINDER

Condition of cylinder	Stream Velocity ft./sec.	Time of Operation Min.	True Conc. p.p.m.	Sample Conc. p.p.m.	Increase in Conc. p.p.m. per min.
Smooth	1.7	20	54	314	13
Smooth	1.1	22	4	1370	62
Flap Valves	1.1	23	3	605	26

Because of the limited scope of these experiments, no conclusions can be drawn as to the weight which this phenomenon should be given in arriving at the accuracy of the instantaneous horizontal trap sampler.

The tube used in the tests had a smaller diameter in proportion to its length than is generally found in existing types of samplers and it is probable that this did produce relatively larger sediment deposits within the tube. The sediment used was also much coarser than that usually found in streams which would also result in larger deposits. The deposition occurred only under a narrow range of velocities and turbulence conditions which might rarely be duplicated in natural streams. The experiments demonstrate only that under favorable conditions, deposition may occur in some types of these samplers.

V. INACCURACIES DUE TO SEDIMENT ADHERING TO SAMPLERS

24. Source of error in transferring samples--In most of the instantaneous trap samplers and in some of the integrating samplers, the containers are not removable and the sediment samples when collected in them must be poured into other containers for shipment to the laboratory (Report No. 1, Section 45). Difficulties are commonly experienced in removing all the sediment from a container without rinsing with excess clean water. Even with intense shaking of the sample as it is poured out, some of the fine sediment may adhere to the walls of the container and some of the coarse particles may fail to pour out with the water. As the total amount of sediment in ordinary samples is usually small, the loss of a minute amount of sediment may constitute a large error in the concentration of the sample.

The magnitude of an error of this nature, varying as it does with the features of the sample container, the characteristics and amounts of sediment, and the details of the emptying technique, cannot be established for all conditions without exhaustive tests. A few tests were made to indicate the order of magnitude of errors which might occur with several common samplers.

25. Test procedure--The sample containers of three representative samplers were tested to determine the amounts of sediment which might be retained in them when their samples were emptied. These samplers were the Vicksburg horizontal toggle trap sampler, the Omaha time-integrating sampler, and the Rock Island simplified time-integrating sampler as described in Sections 66, 90, and 88, respectively, of Report No. 1.

The horizontal cylinder of the Vicksburg sampler was removed from the weight so that it could be shaken more vigorously when emptying the sample. Because the sample container of the Omaha sampler is removable and can be sent directly to the laboratory for sample analysis, loss of sediment by adherence to the container was not considered a problem, but tests were made to determine the amounts of sediment adhering to the cork float device within the sampler. The Rock Island sampler was suspended to facilitate shaking and emptying the samples.

For each determination, the sampler was filled with a suspension of distilled water and a known weight of sediment. This fixed sample was thoroughly mixed by vigorously shaking the sampler, and then was quickly poured out for an analysis of its final sediment content. The sediment left in the sampler was washed out and dried to provide a direct check of the amount lost from the sample. Five determinations were made, using as nearly as possible the same technique for each condition and sampler tested.

The tests of each sampler consisted of a series of determinations with each of four sizes of sediment, 0.01 mm., 0.06 mm., 0.15 mm., and 0.45 mm., at concentrations of 500 and 100 p.p.m. The Rock Island sampler also was tested with each size sediment at 2000 p.p.m. concentration.

26. <u>Test results</u>--Results of the tests are presented in Table 2. Each value given in the table is a percentage of the total sediment in the original sample and is an average value based on five separate determinations. The individual determinations varied considerably, being as much as 50 per cent above or below the average value.

TABLE 2

SEDIMENT RETAINED IN SAMPLERS; PER CENT BY WEIGHT

Sediment m.m.	Rock Island 500 p.p.m.	Rock Island 1000 p.p.m.	Rock Island 2000 p.p.m.	Vicksburg 500 p.p.m.	Vicksburg 1000 p.p.m.	Omaha 500 p.p.m.	Omaha 1000 p.p.m.
0.01	2.2	3.5	2.3	2.1	2.4	1.3	1.1
0.06	9.3	6.0	2.1	12.5	8.2	2.1	1.9
0.15	7.6	6.2	9.0	18.4	8.0	1.9	3.7
0.45	8.6	4.9	9.6	15.4	9.6	0	0

These data show that appreciable amounts of sediment may be retained in a sampler when a sample is poured out into another container. The residues indicated are probably smaller than would result under average field conditions because the vigorous shaking just prior to pouring the samples out in these experiments is less favorable to deposit than when a sampler is being raised up and emptied under comparatively quieter field conditions. The errors in tests with the Omaha sampler were due entirely to the deposit of sediment on the float closing device, and these were apparently less in magnitude than the errors with the other samplers. No correlation of the sampler, the sediment size and concentration, and the resulting errors was obtained.

It should be noted that the values in Table 2 indicate the per cent of material retained in the sampler and are not necessarily the errors which would result in taking consecutive samples. Assuming that the sampler was clean prior to taking the first sample, the residues indicated in Table 2 are typical of the errors in the first sample. If the deposits left from the first sample in a sampler of the horizontal trap type were washed out by the flow through the tube before taking the following samples, the residues would also be representative of conditions for subsequent samples. In horizontal tube sampler if previous samples are not entirely cleaned out, and in samplers like the Rock Island type, where no currents flow through the container, the deposits from one sample washes out more or less into subsequent samples, with a general tendency to increase samples of low concentration and decrease those of high concentration. However, if the same samples were more thoroughly cleaned out than others, in some cases high concentrations would be increased and low ones decreased. Much more extensive research would be necessary to evaluate the importance of errors due to this cause in stream observations.

VI. FILLING CHARACTERISTICS OF SLOW FILLING SAMPLERS

27. Nature of tests--The filling action of a number of suspended sediment samplers of the slow filling, rigid container type was studied in various sampling depths and stream velocities. The test was designed to secure basic information necessary in making a theoretical analysis of the depth-integration method of sampling a vertical as performed by two common samplers, and to allow a practical correlation of the results of the tests of various entrance conditions, presented previously in this report, with the actual filling characteristics of existing samplers. The tests of the entrance conditions showed that the sampling or filling rate was one of the most important factors affecting the accuracy of the sediment concentrations in the samples collected.

These tests of samplers involved the determination of:

a. Filling characteristics in still water.

b. Initial inrush or effect of initial pressure differential.

c. Effectiveness of filling rate adjustments such as varying size of intake and size of air exhaust.

d. Effect of lowering and raising a bottle type sampler upon its filling rate.

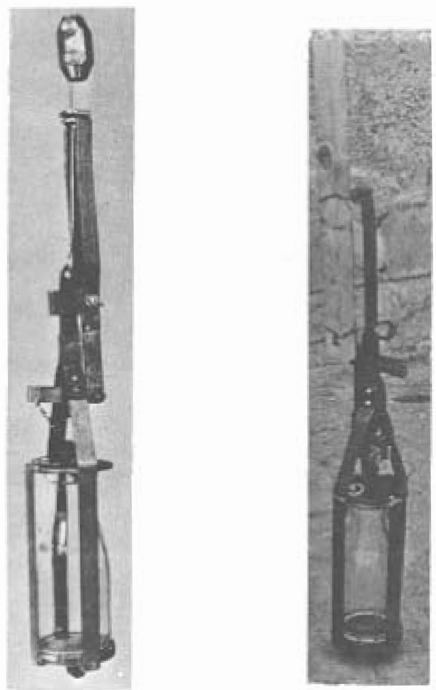
e. Effect of stream velocity on filling rates.

28. Samplers tested and their alterations for test--The samplers tested represent types of slow filling samplers and, except for the Frazier sampler, which is a relatively new design, have been extensively used in sediment investigations. In making the tests it was necessary to open or close the sampler at any desired depth or time and the samplers were

altered, where necessary, to allow this operation. Descriptions of the five samplers tested, with details of the alterations, are given in the following paragraphs:

a. Colorado sampler--The Colorado sampler, shown in Fig. 40a, which was developed and used by the U. S. Geological Survey, consists essentially of a pint milk bottle suspended in a simple frame. The bottle is capped by a rubber insert having a hole of such diameter as to obtain the desired rate of filling. Prior to sampling, the hole is closed with a rubber stopper. At the desired sampling point, the stopper is removed by a simple lever system actuated by the impact of a messenger weight dropped down the suspending cable. No provision is made for closing the bottle after the sample is collected. When necessary, a current-meter weight may be suspended from the bottom of the sampler.

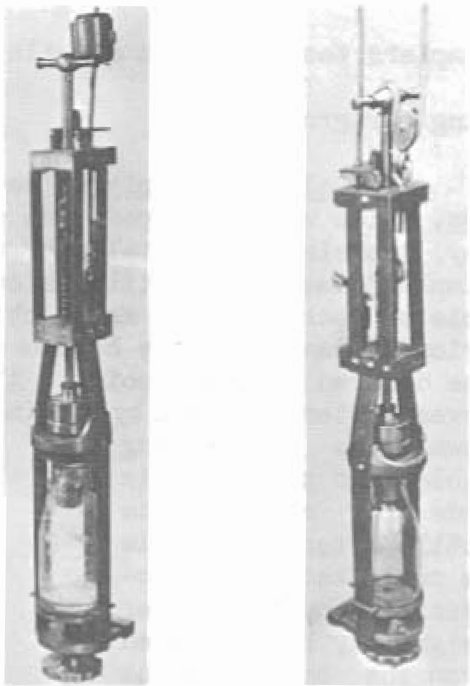
In the altered form of this sampler, illustrated in Fig. 40b, the lever system was reversed so that the weight, when dropped down the suspension line, closed the sampler by forcing the rubber stopper into the bottle opening, instead of removing it. A pull on an auxiliary line opened the sampler. At shallow depths the opening mechanisms were actuated by a rod in place of the drop weights.



a. original sampler b. sampler with alterations

Fig. 40--U.S.G.S. Colorado Sampler

b. Straub sampler--The Straub sampler, shown in Fig. 41a, also utilizes a pint milk bottle for the sample container. The bottle is clamped securely in the sampler frame between two rubber faced grips, the lower one being adjustable by means of a heavy screw. Prior to sampling, the bottle is closed by a valve which is seated over a 1-in. opening in the upper bottle grip. A trigger mechanism holds the valve in the closed position against the tension of a coiled spring. A messenger weight dropped down the suspension line trips the trigger and the valve is raised by the spring to the open position. The water sample flows through the opening, and when full, the sampler is closed by a cork float within the bottle. Current meter weights may be added below the sampler, if necessary.

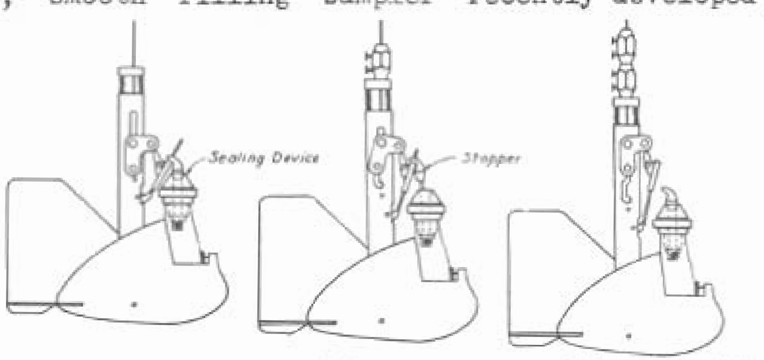


a. original sampler b. sampler with alterations

Fig. 41--Straub Sampler

In using the sampler in these tests it was opened as in the original design. To close the sampler at the desired time, required that the handle actuating the closing valve be forced downward. This was accomplished by an auxiliary line attached to the handle and linked through a pulley on the frame of the sampler, as shown in Fig. 41b. When this line was pulled, the cover mechanism was forced down over the intake and locked in the closed position by the catch.

c. Frazier sampler--The Frazier sampler, shown in Fig. 42, is a slow, smooth filling sampler recently developed by the



(a) - This sampler ready to be submerged. The stopper is sealed in intake tube.

(b) - The first weight has been dropped, raising stopper from intake tube allowing the bottle to fill.

(c) - The second weight has been dropped. The stopper has been released from the trip mechanism and has been pulled back into the bottle by the spring

Fig. 42--Sketch of Frazier Sampler showing method of operation.

U. S. Geological Survey. The sample container is a pint milk bottle clamped into a recess in a streamlined bronze weight. A sealing device inserted in and covering the mouth of the bottle has a 5/8-in. diameter hole at the top through which moves a 5/16-in. diameter tube, with a stopper at the top for closing the 5/8-in. hole. This tube, in addition to guiding the stopper serves as an air exhaust, the air escaping through two 1/16-in. diameter vents located at the top near the stopper in the downstream side. The sample enters the 5/8-in. hole in the insert in the area not obstructed by the tube. The rate of filling may be controlled by varying the distance the stopper is lifted above the opening. The double trip mechanism for opening and closing the bottle is built into a flat stainless steel tube which also acts as the connection between the bronze weight and the suspension cable. A messenger weight dropped down the suspension cable depresses a plunger and allows the heavy bronze weight to drop 1 in. By this action the stopper is raised from the sealing device and the water flows into the sampler. At the impact of a second messenger weight, another trip action releases the stopper which is pulled back into the sealing device by a small coil spring and closes the sampler. The trip mechanism, utilizing the bronze weight for the motivating force, is very positive in action. Since this original design provided for both opening and closing, the sampler was adaptable for these tests without alteration.

d. Omaha sampler--The Omaha sampler, shown in Fig. 43a, is a smooth filling time-integrating sampler designed by the Omaha U. S. Engineer District of the War Department and has been used in extensive sediment investigations in that district. The sample container is a wide-mouth glass jar, of one pint

a. original sampler

b. sampler with alterations

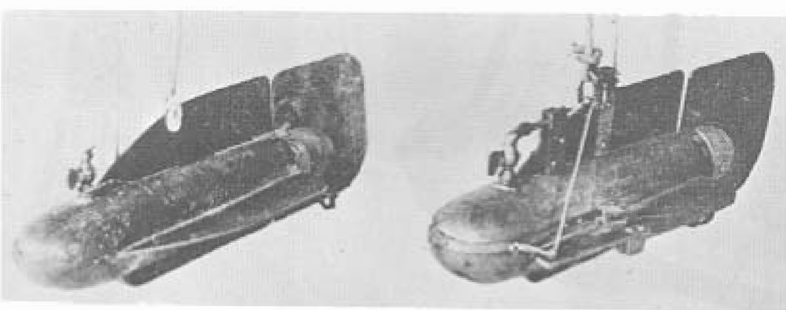
Fig. 43--Omaha Sampler

capacity, that is entirely enclosed in a recess in a streamlined weight. The brass screw cover for the container has a 1/4-in. diameter orifice for the water intake and a 1/4-in. diameter tube for an air exhaust. This tube extends vertically about 1.5 in. up from the cover and has the top cut obliquely so that the opening for air escape faces downstream only.

A large cork float, suspended beneath the lid, closes both intake and the air exhaust tube when the bottle is full, but no provision is made for keeping the sampler from filling during its descent to the desired depth. To accomplish this for these tests, the sampler was altered as shown in Fig. 43b by providing stoppers which could be pressed against both the water intake and air exhaust openings by means of a rigid handle extending above the water surface.

e. Rock Island sampler--The Rock Island sampler, shown in Fig. 44a, consists essentially of a horizontal sample container with an intake tube and controlled air exhaust. The intake opening, 1/4-in. in diameter, is flush with the upstream end of streamlined sample container, and faces directly into the stream flow. The air exhaust tube, 3/16-in. inside diameter, extends upward and is inclined downstream to provide suction for the evacuation of air from the sampler. The exhaust tube is provided with a brass stop cock which is adjustable to regulate the rate of air escape so that the rate of filling may be controlled. No provisions are made for opening or closing the samplers.

The sampler was altered by the addition of rubber pad stoppers which were held in place over the water intake and air exhaust openings by springs. These are illustrated in Fig. 44b. To open the sampler these were held away from the openings by maintaining tension on an auxiliary line. By releasing the pull, the stoppers were forced back over the openings by the springs, closing the sampler.



a. original sampler   b. samplers with alterations

Fig. 44--Rock Island sampler

29. Test procedure--The procedure in making the test will be described individually for the three basic conditions considered.

a. Filling characteristics in still water--The tests in still water were made in an abandoned quarry where depths greater than 50 ft. were available. An ice cover facilitated the work. The samplers were suspended by a cable from a winch which rested upon the ice and permitted lowering and raising the samplers as desired through holes or slots cut in the ice.

For a selected depth the filling data for a sampler was secured by lowering the closed sampler to the desired point and then opening for a short period of time. The periods of time allowed for filling varied from 1 sec. up to a time necessary to fill the container. The volume of each sample as measured in a graduated cylinder was plotted against the corresponding filling time producing filling curves whose slopes represent filling rates. This procedure was followed for a number of depths with each sampler.

For the Rock Island and Frazier samplers the effect of the size of the air exhaust opening and of the size of the intake opening, respectively, were studied using this same procedure.

b. Vertical transit--Effect of vertical motion of the Colorado sampler upon its filling rate was determined for a limited range of conditions. As with the filling determinations in still water, the filling rates were necessarily determined indirectly from a time-volume relationship established by a number of individual observations. Each observation, with sampler descending, consisted of lowering the open sampler at a uniform rate, 1 or 2 ft./sec. used in these tests from the surface to a selected depth where the sampler was closed. By securing a number of samples at different depths, corresponding to the various times allowed for filling, the filling rate was determined.

Individual tests with sampler ascending were made by first lowering the closed sampler below the selected depth of opening. The uniform rate of raising was then established, and the sampler was opened as it passed the desired depth. It was left open for a known period of time, which established the depth range sampled. A series of such samples, differing only in time allowed for filling and consequently the depth at which the sampler was closed, was obtained for each of two depths of opening with each of two rates of raising.

c. Flowing water--The tests to determine the effect of stream velocity upon the sampler filling rates were made in a large flume 10 ft. wide and 114 ft. long, which was equipped with a controlled head gate and with a bulkhead at the downstream end. Velocities up to 6 ft./sec. were attainable, and the actual velocity at the sampling point was measured with a Price current meter. The samplers, with the exception of the Frazier, were suspended in this flume as illustrated by Fig. 45. The Frazier sampler was not tied to the bottom of the flume, but was held against the current by a stay wire attached to its nose. Each sample was collected by lowering the closed sampler to the sampling point in the known stream velocity and opening it to allow filling for a definite period of time. From a sample so collected, the volume entering in the first second, termed initial inrush, which is discussed in Section 30, was subtracted and only the remainder used in the filling rate computation.

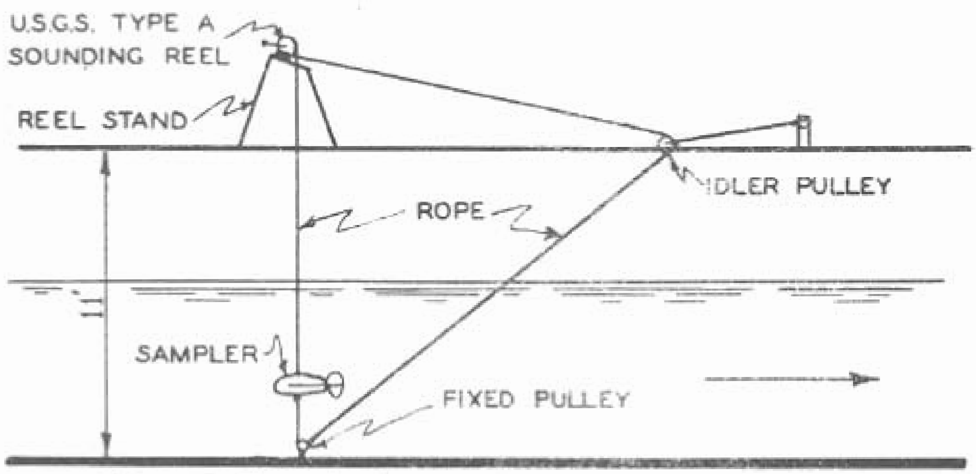


Fig. 45--Method of suspending samplers in flume.

30. Filling characteristics--The results of the tests at various depths in still water, with all the samplers except the Omaha, are presented in Fig. 46. These plotted data show the quantity of water collected during the time the sampler was open, and the slope of a curve at any point represents the filling rate. Results of tests with the Omaha sampler are not presented because of irregularities in the data; the reasons for which will be discussed in a later paragraph of this section.

An analysis of these curves reveals two important filling actions, which are characteristic of all the samplers tested.

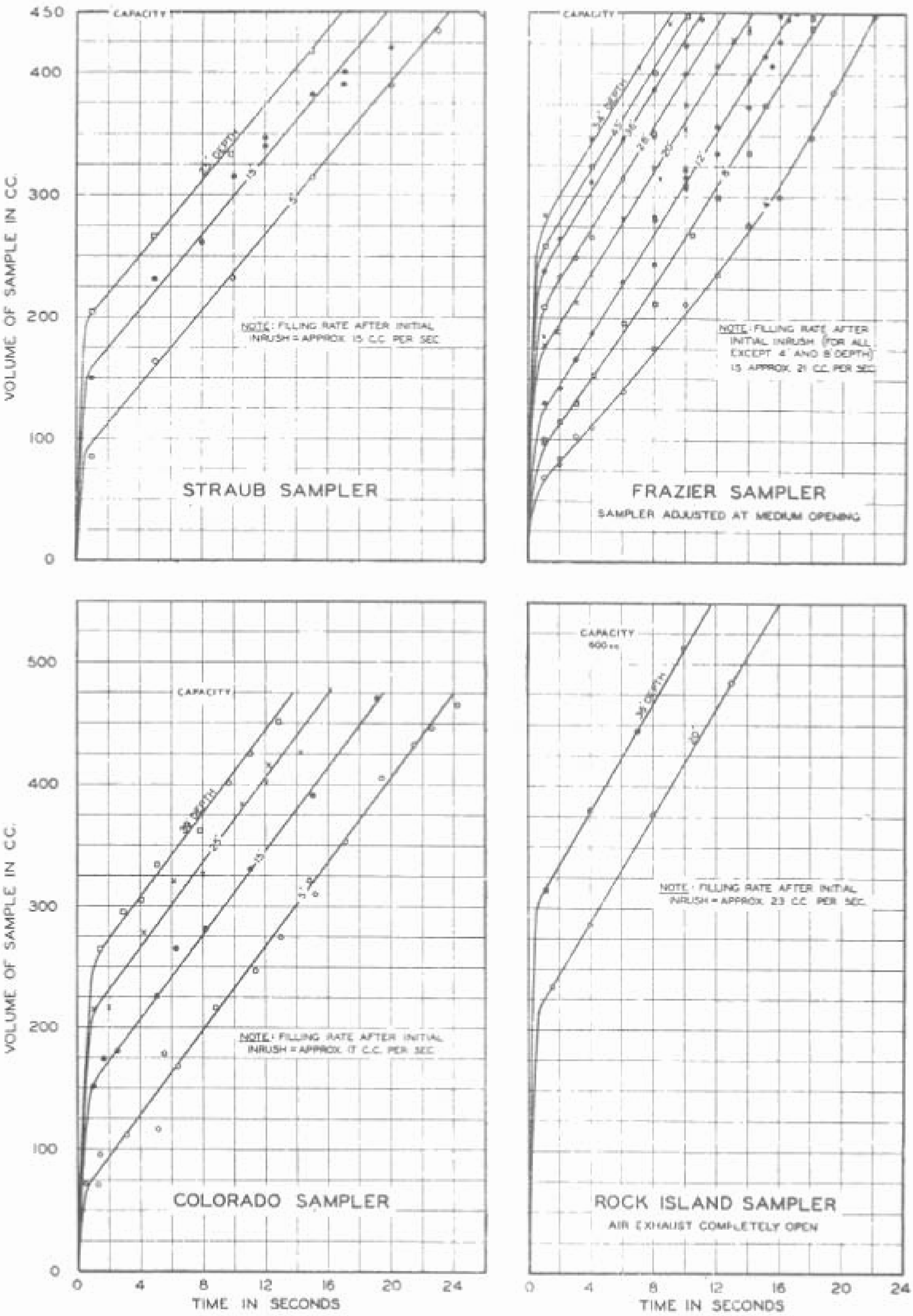


Fig. 46 - Filling characteristics of samplers in still water.

a. Initial inrush--Immediately a sampler is opened, an inrush of water occurs, which is volumetrically a function of the depth of submergence, and may represent a considerable percentage of the total sampler capacity. It is termed initial inrush in this report because of its high rate of inflow.

b. Normal filling--The average filling rate, after the initial inrush, is substantially a constant for any one sampler and is unaffected by the depth of sampling. It may be either uniform and smooth, if a separate air exhaust is provided, or intermittent if a single opening must serve for both air escape and sample intake.

The initial inrush represents the volume decrease of the air within a sampler, corresponding to its compression from atmospheric pressure to the hydrostatic pressure at the particular sampling depth. During this action no air escapes and the filling rate is a function of the pressure differential from outside to inside the sampler. At the instant the sampler is opened, this pressure differential is a maximum, equal to the full hydrostatic pressure at the sampling point, and, consequently, the filling rate is a maximum. Both pressure differential and filling rate are quickly reduced as the air in the sampler is compressed, and when the pressure differential reaches zero, the filling becomes the normal action involving a displacement of air. The initial inrush period was found to be less than 1 sec., but because of the inability to collect samples for shorter periods, the quantity collected during the first second after a sampler was opened was considered as resulting from initial inrush.

After the initial inrush, and the compression of the air to a pressure practically equal to the hydrostatic pressure at the depth is completed, the filling takes place as a displacement of air caused by the buoyancy of the air. For each volume of water entering the sampler an equal volume of air escapes and the filling rate is affected by the sampling depth. It may be smooth and uniform if a separate opening is provided for air escape, but is intermittent and irregular when the air must interrupt the sample inflow to escape through the same opening.

From the still water tests with all the samplers, the initial inrush quantities of the individual samples, expressed as percentages of the sampler capacity are plotted in Fig. 47. The theoretical values of the air volume decrease, for various depths, were computed by Boyle's gas law and are also plotted on Fig. 47. The close agreement of the experimental and theoretical curves, with less than 1 per cent deviation, verifies the

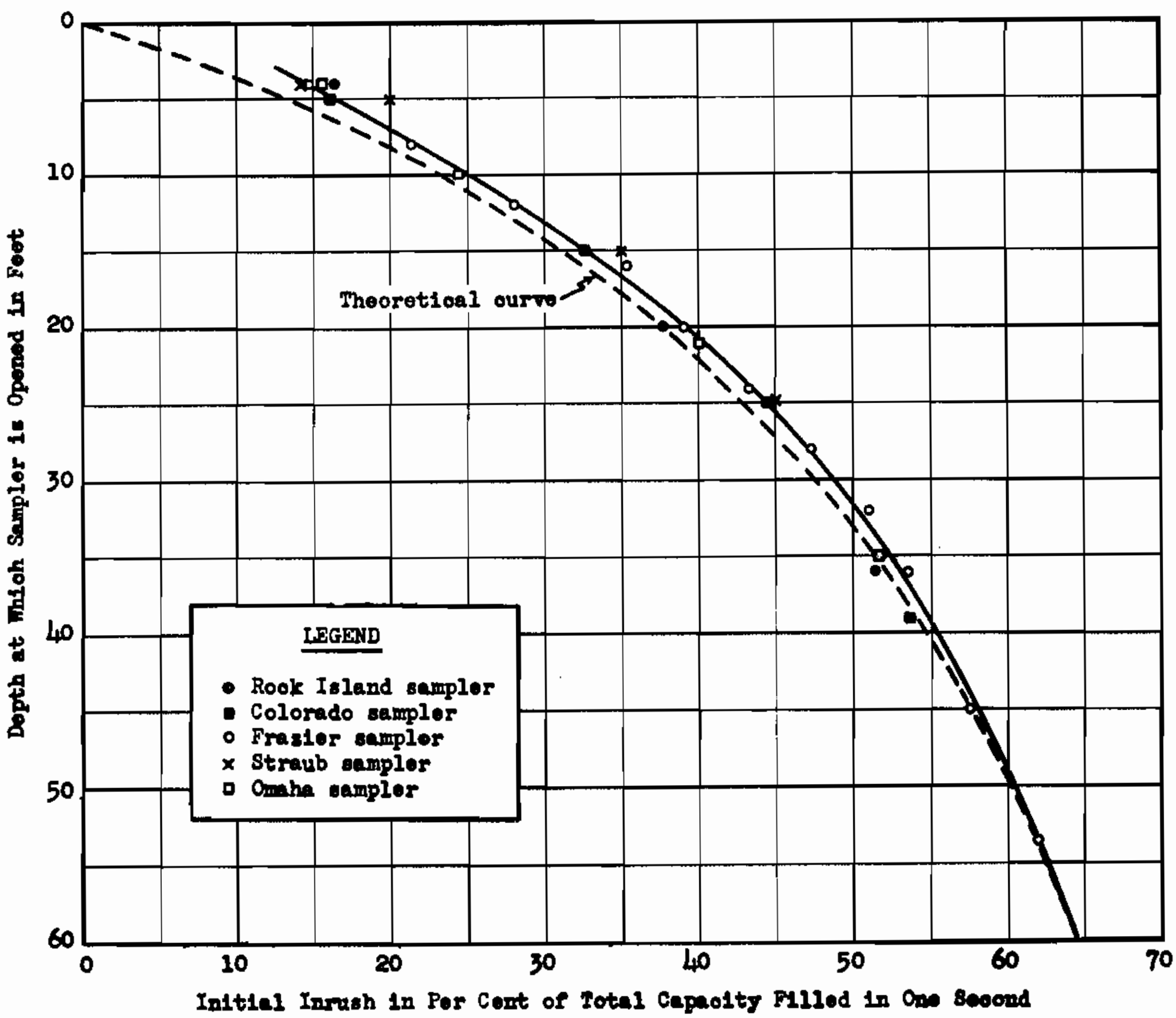


Fig. 47--Initial inrush into slow filling, rigid container samplers.

analysis of the initial inrush phenomena. The slightly greater experimental values of initial inrush may be attributed to the fact that the quantity collected during the first second of sampling was considered the volume of initial inrush whereas, undoubtedly, it entered the sampler in less than 1 sec. The curve, representing data with all the samplers tested, indicates that the initial inrush-sampling depth relationship established, is applicable to all existing samplers of the rigid container type.

The initial inrush phenomena is an important consideration in sampling with slow filling rigid container samplers when the sampler is opened at some point below the surface. There are two actions that may result in serious errors in the sample collected.

> _a_. The excessive sampling rate during the initial inrush period may result in a segregation of the sediment from the water and a sample too low in concentration. Dependent upon particle size, this phenomena may be serious as determined in the study of entrance conditions presented in Chapter III.
>
> _b_. With the opportunity for a relatively large portion of the sample container to be filled in less than 1 sec. the sample secured is not a true time-integrated sample and may not represent an average value of sediment concentration at the sampling point. Or, when used for the depth-integration method where the sampler is to collect a sample only while being raised, too large a portion of the sample will be collected near the bottom. In this case, the increase in concentration resulting tends to offset the decrease as described under _a_ above.

The normal filling action of the samplers not provided with separate air exhausts was intermittent and irregular because of the air escape. This action apparently consisted of a period during which the filling decreases and finally stops, followed by an instant of air escape or bubbling. At times, especially in still water, the air escape was delayed, possibly because of the surface tension of the water at the sampler mouth, and there would be a period of neither filling nor air escape. This clogging action was prevented in the tests by agitating the samplers to allow normal intermittent filling. This difficulty has been experienced by several field observers using the samplers under actual stream conditions.

With the Omaha sampler, although it was provided with separate air exhaust to allow smooth uniform filling, the filling action in still water and in low stream velocities was intermittent and subject to the clogging action. This may be attributed to a tendency for the air to escape and the water to enter through both the air exhaust tube and the intake orifice.

With the Rock Island sampler, and in other slow filling samplers of similar design, a condition in field operation was observed which should be avoided. When this sampler becomes tilted nose downward, air is trapped in the back end of the sample container and cannot escape. The sampler may fill until water is passing through and out the air exhaust, yet the sample volume will not indicate that the sampler is entirely filled. Under this action there exists the opportunity for deposition of sediment in the sampler, resulting in an abnormally high sediment concentration.

31. Effectiveness of filling rate adjustment--The Frazier and Rock Island samplers were tested to determine the effectiveness of the adjustment provided to regulate their filling rates. On the Frazier, the effective size of the mouth may be changed by varying the distance the stopper is raised from the mouth. On the Rock Island, the air exhaust may be throttled by a stop cock valve.

Results of the tests with the Frazier sampler adjusted to large, medium, and small openings are shown by Fig. 48. The filling rates of 46, 21, and 5 cc./sec., respectively, show positive and effective control. These data were secured at a depth of 45 ft., but data at a depth of 20 ft. gave corresponding results. The filling rate after initial inrush for each adjustment of the stopper does not vary with depth. This is also shown by the test data presented in Section 30.

The results with the Rock Island sampler for two adjustments of the air exhaust are presented in Fig. 49. From a filling rate of 23 cc./sec. with the air vent open, the rate was reduced to 15 cc./sec. by turning the valve to the half closed position.

The desirability of throttling the filling rate of the Rock Island sampler is questionable, however, because of the errors in sediment concentration which were found to occur from an intake rate below normal as described in Section 14. Even without throttling the air exhaust, the sampling rate would be lower than the desired normal rate.

32. <u>Effect of lowering and raising the Colorado Sampler upon filling characteristics</u>--The Colorado sampler, selected as a sampler commonly used in the depth-integration method of sampling, was tested to determine its filling characteristics under various conditions of lowering and raising. The test procedure is described in Section 29. The tests with the descending sampler consisted of two series of samples collected as the sampler was lowered from the surface at rates of 1 ft./sec. and 2 ft./sec. The tests with the ascending sampler consisted of two series of samples collected as the sampler was raised from each of two opening depths at rates of 1 ft./sec. and 2 ft./sec. Results of these tests are presented in Fig. 50.

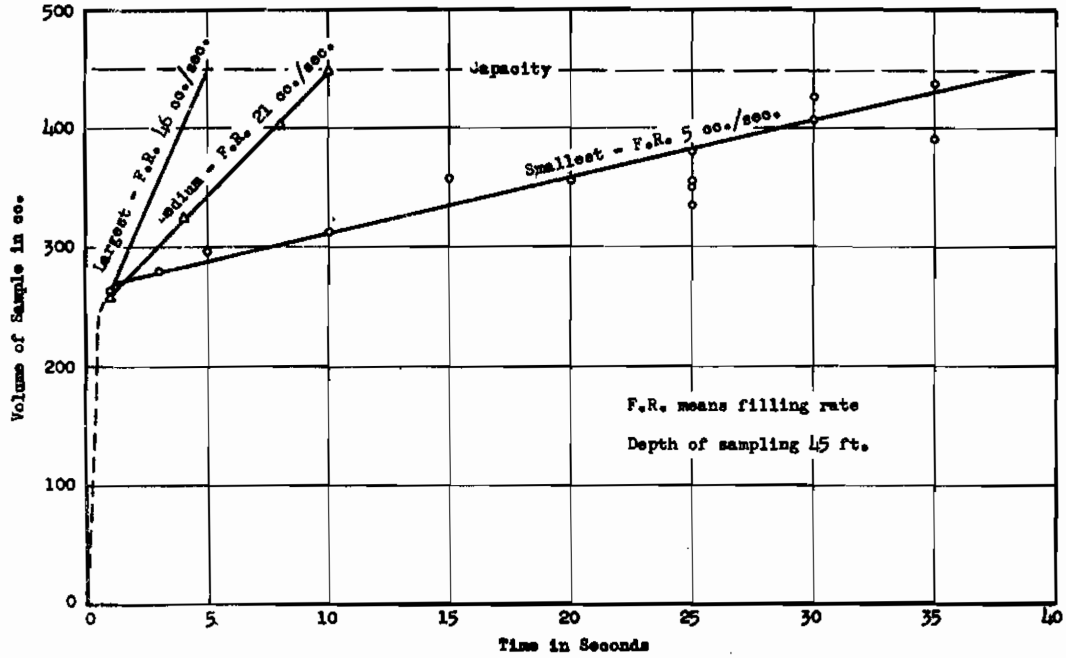


Fig. 48 - Effect of size of opening in Frazier sampler upon filling rate.

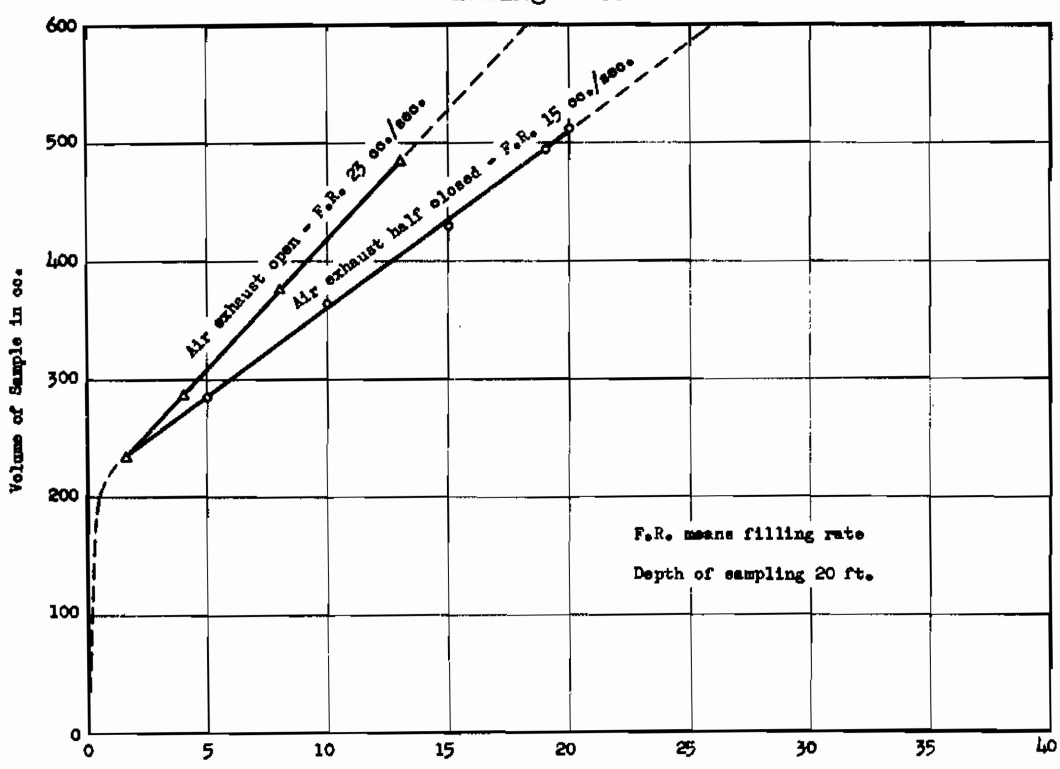


Fig. 49 - Effect of air exhaust adjustment upon filling rate of Rock Island sampler in still water.

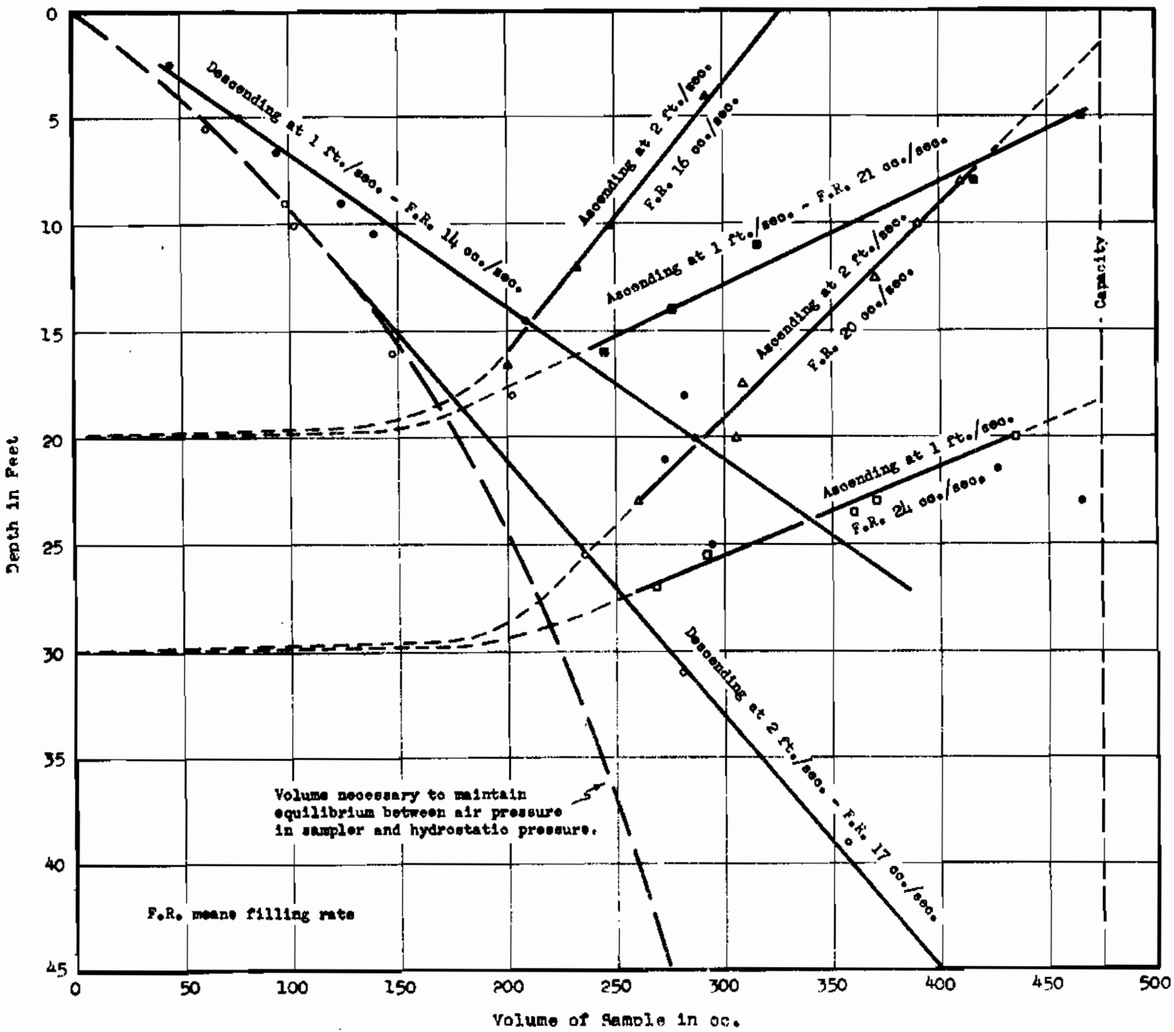


Fig. 50--Filling characteristics of Colorado sampler with vertical movement in still water.

The filling of the descending sampler is a combination of filling which corresponds to the continuous air compression and of filling which replaces the escaping air. The proportions of each varies with lowering rate. Their relative magnitudes at any time depends on depth and lowering rate. Comparing the filling curves resulting from tests with the descending sampler with the theoretical inrush volume curve, it is evident that a large percentage of the filling corresponds to the compression of the air volume in the sampler. For the 2 ft./sec. lowering rate there was no appreciable air escape until a 15-ft. depth was reached. From that level downward the rate of pressure equalization was more rapid, relatively, allowing time for air release and normal filling. With a decreased rate of lowering, illustrated by the 1 ft./sec. curve, the time for air release is greater, allowing normal filling to occur at shallow depths.

The average sampling rate is slightly greater for the 2 ft./sec. rate of lowering than the 1 ft./sec. but the difference is probably not significant because of considerable deviation of individual observations from the general curve for the 1 ft./sec. lowering rate.

The filling of the ascending sampler, after inrush has taken place, is entirely an action of displacement of the escaping and expanding air, and thus is similar to the normal filling action of a sampler stationary at a depth after initial inrush has occurred. In the tests made the initial inrush was volumetrically proportional to the depth at which the sampler was opened, the same as in the tests with the sampler stationary at a depth. The rates after the inrush are practically uniform and, except for the 2 ft./sec. raising rate from the 20 ft. depth, are appreciably higher than the corresponding results with no vertical movement.

Further analysis of these results and general conclusions are not attempted because the filling action of the Colorado sampler with vertical movement is complicated by the disturbance of the mechanism above the sampler mouth. Considering the variations in individual observations and the artificial agitation found necessary to insure filling, these data serve only to show that for the Colorado sampler the filling rate may be considered constant for all practical rates of raising and lowering.

33. <u>Effect of stream velocity on filling rates</u>--The results of the filling rate determinations with the samplers in various stream velocities are shown by Fig. 51. The filling rates plotted for each respective stream velocity represent the filling after initial inrush obtained as an average of from 10 to 15 individual samples which varies over a range of about 20 per cent.

From these results it is seen that the Rock Island sampler, with its mouth facing into the stream, is the only one of the samplers tested which exhibits a definite relationship between filling rate and stream velocity.

With the Straub, Frazier, and Colorado samplers, with intakes facing normal to the stream, the stream velocity did not significantly affect the filling rates, Any slight variations in filling rate which these samplers appeared to have with various stream velocities are accidental and probably result from indirect effects such as agitation and better air escape. With the Omaha sampler, whose mouth also faced normal to the stream, but whose air exhaust was faced downstream there was no appreciable effect of the stream velocity upon the filling rate.

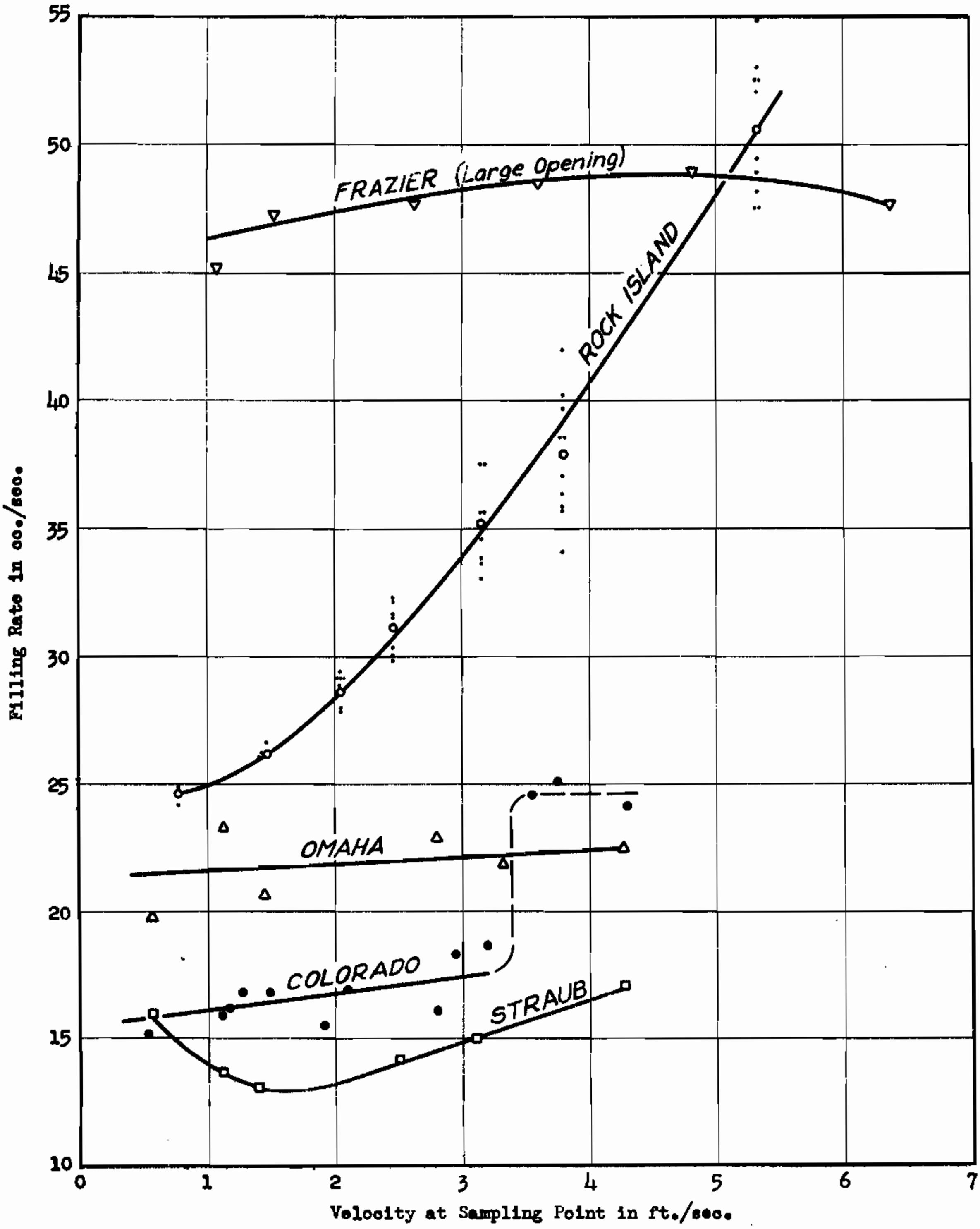


Fig. 51 - Effect of stream velocity upon filling rates.

FIG. 51

VII. SUMMARY AND CONCLUSIONS

34. Summary of sampler studies--Report No. 1 of this project included a review of suspended sediment samplers, which consisted of classification, descriptions, and general discussions of the samplers. Certain features of sampler design and operation were suspected of affecting the accuracy of samples collected and the general adaptability of the samplers. Although these features and their effects could not be reliably analyzed in that review, they were listed as follows:

a. Disturbance of normal stream flow and the tendencies toward segregation of water and sediment as the sample is being collected.

b. Filling due to initial pressure differential, resulting in a non-representative filling rate.

c. Non-removable sample containers which tend to loose sediment when the sample is transferred to another container.

d. Instantaneous sampling action as related to fluctuations of sediment concentration in the stream at the sampling point.

e. Inability to collect a sample close to the bed resulting in an inadequate sample of the larger material being transported.

f. Mixing of sample with water-sediment above the sampling point resulting in an unrepresentative sample.

Features a, b, and c have been studied experimentally and the results are presented by this report.

The disturbance of normal stream flow at the sampler entrance and deposition during the flow through a horizontal cylinder have been found to have considerable effect upon the sediment concentration of samples. The filling due to initial pressure differential, termed initial inrush in this report, was investigated in the experimental study of the sampler characteristics. Conclusions from these studies are presented in subsequent sections.

In Report No. 1 was pointed out the possibility of obtaining with an instantaneous sampler a value of sediment concentration not representative of the average at that point due to the fluctuations in sediment concentration caused by turbulence. These fluctuations were not studied in this project and since the few experimental data available do not define the magnitude of these errors nor the conditions under which they become important, the errors can be determined approximately taking duplicate samples and comparing their concentrations. Under conditions where important differences are found, a sufficient number of samples should be taken to obtain a reasonably accurate value for the average concentration.

The inability to collect a sample close to the stream bed is a design feature as are various other minor factors affecting the adaptability of a sampler. The necessity of sampling close to the stream bed, if representative particle size-discharge relationship is to be secured, is discussed in Report No. 3.

The intermixing of water-sediment from above a sampling point into a sample is obviously undesirable when a sample representing a particular depth is desired. It is primarily a consideration in sampler design.

35. Study of sampler entrance conditions--The flow conditions of a suspended sediment sample approaching and entering a sampler have been analyzed and the tendencies toward segregation of the water and sediment as a result of deflection or disturbance of the flow have been evaluated for the resulting errors in the sediment concentration of the samples.

From these studies, errors of serious magnitudes were found to result from certain, not unusual, entrance conditions and were found to vary significantly with the factors listed below:

a. Size of sediment--The size of the sediment particles was established as one of the more important factors affecting the magnitude of errors which result from undesirable intake action. The size, 0.06 mm., approximately the upper limit of Stokes' law, appeared as a critical size above which the errors increased rapidly in magnitude as the sediment size increased, and below the 0.06 mm. size the variation in the magnitude of errors, as the sediment size varied, was considerably less. Below 0.06 mm. the errors for all conditions studied were less than 10 per cent. For particles larger than 0.06 mm., which are not uncommon, the results have immediate practical application in proper sampler design or selection.

b. Orientation of sampler intake--It was found to be essential in order to collect accurate samples, that the sampler mouth face into the stream. Although a nozzle facing directly into the stream is the desirable condition, small deviations up to 20° from this orientation, as might occur accidentally in the operation of a sampler, have little effect upon the sediment concentration.

c. Sampling rate--The sampling rate was found to be the most important factor in the operation of a slow filling sampler, for serious errors may occur, particularly when the sampling rate is appreciably slower than the stream velocity. The sampling rate must either be controlled so that the velocity in the mouth is approximately equal to the normal stream velocity at the sampling point or the sampler must be calibrated for its ratio of intake velocity to stream velocity and correction curves determined similar to the curves shown in Fig. 13. Any control of a sampling rate or calibration of a slow filling sampler is complicated by the extremely rapid entrance of water during the initial pressure equalization that has been shown to occur within less than 1 sec.

d. Shape of sampler intakes--It was found to be essential that the mouth of the sampler be extended upstream from any deflection or disturbance of the flow caused by the body of the sampler. No absolute values of the required length of this extension were determined but it was demonstrated that a mouth flush with the body of the sampler is not satisfactory. The actual shape of the nozzle should approximate the streamlined shape of the standard nozzle as nearly as practical but not at a sacrifice of simplicity and ruggedness as small variations in shape of the nozzle were found to be unimportant.

e. Area of sampler mouth--The area of the sampler mouth, although found to affect somewhat the magnitude of errors that do occur did not affect the accuracy of samples collected under the properly controlled standard sampling conditions. The tendency was toward larger errors with smaller mouth sizes. It is more important that the extreme leading edge of the sampler mouth, as illustrated in Fig. 17, be used in computing the area to be used in determining the intake velocity. The area of the mouth of a slow filling sampler should be determined from considerations of the volume of the samples to be collected, the desired duration of sampling time, and the range of stream velocities.

Although the factors listed above have been discussed primarily as pertaining to slow filling or time-integrating samplers, the considerations are applicable also to the instantaneous horizontal samplers. The conception of the phenomena of streamline deflection and disturbance is also applicable to the study of the vertical trap instantaneous samplers.

36. Flow through horizontal cylinders--The experiments described herein have shown that under certain conditions deposits may occur in samplers of the horizontal trap type, due to the reduction of the vertical components of the momentary currents of the stream as it flows through the cylinder. The studies made were insufficient to evaluate the importance of these errors.

37. Loss of sediment in sample transfer from nonremovable containers--The study of the amount of sediment adhering to nonremovable container samplers when the samples are poured out indicate that even under favorable conditions of agitation, these amounts may be of appreciable magnitude and under certain conditions may lead to errors of considerable magnitude.

The studies were not sufficient to delimit the conditions under which errors of importance would occur.

38. <u>Filling characteristics of slow filling samplers</u>--The filling characteristics of five representative slow filling samplers were determined experimentally. Two distinct filling actions, a rapid inflow to equalize air and water pressures and a normal filling after the equalization, were found to be common to the samplers of this class.

When the samplers were opened at a point below the surface the pressure equalization, termed initial inrush, was found to occur in one second or less with no escape of air during the action; the volume of water entering being proportional to the depth. This action is extremely important in the collection of time-integrated samples. For example, Boyle's Law indicates that at a 34-ft. depth approximately 50 per cent of the sampler capacity would be filled by this initial inrush volume. Important also to consider is that errors in concentration tend to occur because of the excessively high intake rate, a condition which, in the laboratory study of intake action, was found to be serious. The two effects, however, usually tend to offset each other.

In still water, or if the sampler opening does not face into the stream, normal filling after the initial pressure equalization occurs at a more or less constant rate; the action being generally smooth and uniform if the air escapes through a separate exhaust, but intermittent and irregular if the air and sample flow through a common opening. If the sampler faces into the stream, the filling rate logically was found to vary with stream velocity. Although filling rate adjustments were found to be effective in controlling the rates, the procedure is questionable from the standpoint of the accuracy of the sediment content of the samples collected with intake velocities considerably below the normal stream velocities.

The filling action of a common bottle sampler was studied under various conditions of lowering and raising. The rate of filling, whether after initial inrush if the sampler was lowered to a point, opened and filled while being raised, or during constant rates of lowering and raising, was essentially constant. There did not appear to be a substantial difference in filling rates under the various types of movement. This test was not comprehensive and the results are not necessarily applicable to other types of slow filling samplers used in the depth-integration method.